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Editor's Corner

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Every two years, NASA's Earth Science Division (ESD) conducts a Senior Review of missions in (or entering into) *extended operations*—meaning they have completed their prime operations period[1]. This past spring, 10 missions took part in the Senior Review: Aqua, Aquarius, Aura, CALIPSO, CloudSat, EO-1, GRACE, OSTM/Jason-2, SORCE, and Terra[2]. The TRMM mission was also in extended operations at the outset of the Senior Review process, however, it was not invited to propose because of its orbital decay following fuel depletion. (TRMM re-entered the atmosphere on June 16, 2015). All other operating Earth Science missions were still in their prime operations period.

The Senior Review was tasked with reviewing proposals submitted by each mission team for extended operations and funding for FY16–FY19—with the evaluation emphasis on the first two fiscal years. The Science Panel[3] was unanimously impressed that all 10 reviewed missions have made unique and important contributions to NASA Earth science objectives. Collectively, these missions constitute an unprecedented Earth-observation capability that has transformed our scientific understanding of the Earth system, and they provide data for applications of extremely high-societal relevance.

The **Table** on page 2 summarizes the mission-specific findings. Refer to the full report for detailed discussions of each mission. In addition, the panel had the two following findings:

1. **Earth Science Mission Operations (ESMO).** A significant challenge to successful continuation of NASA missions resides in spacecraft health and safety maintenance. The Earth Science Mission Operations (ESMO) is responsible for maintaining several of the reviewed missions (Aqua, Aura, EO-1, Terra). Due to increased risks associated with aging satellites and a flat budget, the panel felt that a review of potential longer-term solutions to the mission operations of these missions should be a priority.

2. **Terra Orbital Maintenance.** To maximize future science with its remaining fuel, the Terra team proposed an orbital maintenance plan to maintain a 705 km altitude and 1030 mean local time (MLT) equatorial crossing for the next few years. However, this would require a waiver from the NASA reentry requirements that were in place at the time of the Terra launch. If the waiver is not granted, the panel agreed that the resulting orbital change would compromise the continuity of the stable long-term climate data records at some level, but felt additional information was necessary to fully assess the significance of product degradation. The panel suggested that a workshop of data users be convened to discuss and evaluate the trade-offs associated with the waiver decision.

While the Science Panel was impressed that the missions continue to operate beyond their designed lifetime (a testament to high-quality engineering, management, and mission execution), it expressed concern that these missions are aging and noted that the risk of losing critical Earth-observation capabilities is increasing.

In our last issue, we reported that the radar onboard the Soil Moisture Active Passive (SMAP) mission ceased transmitting data on July 7 and that the SMAP project was investigating the anomaly. A series of diagnostic

[1] A full report including Appendices with Subpanel reports can be found at *science.nasa.gov/media/medialibrary/2015/07/15/2015_ESDSeniorReviewReport_FINAL.pdf*.
[2] The QuikSCAT mission was also invited to the 2015 Senior Review, but declined to propose, and therefore was not evaluated.
[3] The Science Panel evaluates science in terms of scientific merit, relevance to NASA Earth Science Division science goals, and product quality. Subpanels are convened to provide in-depth evaluations of the national interest, technical performance, and costs of extending each mission.

editor's corner

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Reminder: To view newsletter images in color, visit *eospso.nasa.gov/earth-observer-archive.*

Table. Summary of Mission Specific findings from the 2015 Earth Science Senior Review.

Mission	Science Scores*			Numerical Science Score	Adjectival Summary Science Score	Utility Score	Technical Risk	Cost Risk	Conclusion	
	Merit	Relevance	Product Quality						FY16-17	FY18-19
Aqua	5.0	5.0	5.0	5.0	Excellent	Very High	Low	Low	Continue	Continue
Aquarius	5.0	5.0	4.0	4.7	Excellent	High	Low	Low	Continue	Continue
Aura	5.0	5.0	5.0	5.0	Excellent	High	Medium Low	Low	Continue	Continue
CALIPSO	5.0	5.0	5.0	5.0	Excellent	High	Medium-Low	Medium-Low	Continue	Continue
CloudSat	5.0	5.0	5.0	5.0	Excellent	High	Medium-Low	Low	Continue	Continue
EO-1	2.8	2.9	3.0	2.9	Good	Some	Medium	Low	Terminate & Close-out	[closed]
GRACE	5.0	5.0	5.0	5.0	Excellent	High	Medium-High	Medium-Low	Continue	Continue
OSTM	5.0	5.0	5.0	5.0	Excellent	High	Medium-Low	Medium-Low	Continue	Continue
SORCE	4.0	5.0	4.0	4.3	Very Good	High	Medium-High	Low	Continue	Continue/ Augment
Terra	5.0	5.0	5.0	5.0	Excellent	Very High	Low	Medium-Low	Continue	Continue

* All Science Scores are on a 1-5 scale with 1 being the lowest ranking of "Poor" and 5 being the highest ranking of "Excellent." Additional commentary or conditions on the Panel's scores and/or conclusions are noted in the mission specific findings are in the full report at the URL cited in the text.

tests and procedures were performed both onboard the spacecraft and on the ground using flight spare parts. Unfortunately, we can now report that the radar is likely not recoverable. Investigations traced the problem to a low voltage power subassembly in the radar's high-power amplifier, which is designed to boost the power level of the radar's pulse to more than 500 W, ensuring that the energy scattered from the Earth's surface can be accurately measured. On August 24, the project made a final attempt to power up the radar unit, which was unsuccessful[4].

While the loss of the radar is certainly a setback, the SMAP mission continues. Although SMAP's radar and radiometer were designed to be used in tandem for the highest science return, they function as individual instruments. The radiometer continues to perform well. Based on the high quality of the radiometer data available from SMAP so far, the team has identified that it will be possible to produce other science research quality measurements, such as sea surface salinity and high winds over the ocean surface, in addition to soil moisture and freeze/thaw.

The radar allowed the mission's soil moisture and freeze/thaw measurements to be resolved to 9 km (5.6 mi) or better for soil moisture and 3 km (1.9 mi) for freeze/thaw. Without the radar, the mission's resolution will be limited to areas of approximately 40 km (25 mi) for soil moisture and freeze/thaw. While the resolution is lower with the radiometer alone, the mission will meet its requirements for soil moisture accuracy and produce global soil moisture maps every two to three days

SMAP was launched January 31 and began its science mission in April, releasing an initial global map of soil moisture on April 21. To date, the mission has collected more than four months of science data, approximately two and half months with the radar operating. Beta-quality Level-1 radar and radiometer data have been available since August 1 through the NSIDC and ASF DAACs. SMAP scientists plan to release beta-quality Level-2/ Level-4 soil moisture data products at the end of October, although forward stream processing of some of the beta Level-2 soil moisture data is already available through NSIDC. Validated data release is currently planned for May 2016.

In other news involving current missions, an anomaly with ISS-RapidScat began on August 15 at 03:01:59 UTC (Orbital Rev 5064) and continues as of this writing. There has been a drop in the echo power signal in the receiver of approximately 20 dB. Both noise and signal power dropped—but not by equal amounts. The signal to noise ratio dropped by 10 dB. Corresponding with this drop in power was an increase in the Scatterometer Electronics Subsystem (SES) current. ISS attitude has appeared normal during this time. Due to this anomaly the RapidScat Science Data Systems Team was initially unable to process the telemetry data to backscatter (Level-1b, -2a) or wind vectors (Level-2b). The operations team is still in the process of investigating the cause of the "reduced echo power" anomaly.

There are two changes in the data going forward as a result of this persistent anomaly. The following changes affect all orbits after the anomaly: The wind direction accuracy (and to a lesser extent speed) is degraded for low winds. Winds above 6 m/s are not significantly affected but statistics for winds between 3 and 6 m/s are noticeably worse especially in the middle of the swath; rain flagging is now unavailable for the outer (single beam) portion of the swath.

We can also report that the launch of Jason-3, which had been planned for August, has been delayed due to the loss of the unmanned SpaceX Falcon 9 resupply mission to the ISS on June 28. NASA continues to work with NOAA, CNES, SpaceX, and the Western Range at Vandenberg Air Force Base to identify potential launch opportunities for Jason-3, but no official launch date has been established, as the investigation is still on-going. Jason-3 will continue the ocean surface topography measurements that began with TOPEX/Poseidon and continued with Jason-1 and OSTM/Jason-2.

Finally, two articles in this issue are of special note. The GPM mission is now well into its second year and data are flowing in from the Core Observatory and the nine constellation members. The second GPM Applications Workshop took place this past June. This meeting was an opportunity to formally introduce the capabilities of the GPM Mission to the user community, outline many of the advances of GPM Core over TRMM, and provide overviews of how both TRMM and GPM data products are being used in a broad range of applications. On June 11 there were two, half-day training sessions to further familiarize people with GPM data products, data access and visualization capabilities. A summary of this workshop begins on the next page.

The MODIS imager onboard NASA's EOS Terra and Aqua satellites and VIIRS onboard the Suomi NPP satellite have been collecting data since they launched in 1999, 2002, and 2011, respectively. In May, the MODIS and VIIRS science teams met jointly with an emphasis on data product continuity challenges and progress. Product continuity from the EOS era through Suomi NPP and JPSS missions was the major goal for the current Suomi NPP science team. Turn to page 12 to learn more. ■

Note: List of undefined acronyms from the *Editor's Corner* and the *Table of Contents* can be found on **page 43**.

[4] NASA has appointed a mishap investigation board to conduct a comprehensive review of the circumstances that led to the HPA anomaly in order to determine how the anomaly occurred and how such events can be prevented on future missions. JPL also will convene a separate failure review board that will work with the NASA investigation.

meeting summaries

Measuring Rain and Snow for Science and Society: The Second GPM Applications Workshop

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The Workshop in Context

The Global Precipitation Measurement (GPM) Core Observatory, co-led by NASA and the Japan Aerospace Exploration Agency (JAXA), launched successfully in February 2014. In November 2013 (a few months prior to the launch[1]) the first GPM Applications Workshop[2] took place. Scientists, Earth-observation data users, and *end users* (defined for the purposes of this article as those who use various decision support systems where Earth science data are used as input) gathered to learn how data from the Tropical Rainfall Measuring Mission (TRMM) were (at that time) being applied to a variety of science and societal issues and what was anticipated from GPM. In order to keep the lines of communication between science teams and the user community open, NASA's Applied Science and Precipitation Measurement Missions Science Programs intended this to be the first in a series of workshops. To that end, another workshop was tentatively planned for the spring of 2015.

The GPM Core Observatory is now well into its second year of operations. The larger GPM Mission is comprised of a constellation of nine domestic and international satellites that provide estimates of rain and snow worldwide every three hours. The constellation is centered on the GPM Core Observatory, which includes the Dual Frequency Radar (DPR) and GPM Microwave Imager (GMI).

With data products now rolling in both from the GPM Core Observatory and from the combined constellation via the Integrated MultisatellitE Retrievals for GPM (IMERG) data product, the time was right to assemble the community again. The second GPM Applications Workshop took place June 9-10, 2015, at the University of Maryland Conference Center, in Hyattsville, MD.

In all, there were 108 participants onsite, with up to 30 others participating via *WebEx*. Included among the participants were representatives of government agencies, academia, the private sector, international organizations, and other parties interested in GPM applications. This meeting was an opportunity to formally introduce the capabilities of the GPM Mission to the user community, outline many of the advances of the GPM Core over its predecessor, and provide overviews of how both TRMM and GPM data products are being used in a broad range of applications. On June 11 there were two, half-day training sessions to further familiarize attendees with GPM data products, data access, and visualization capabilities—see *Training Sessions on GPM Data Products* on page 11.

Because of the sheer number of presentations and the depth of technical detail, the summary report that follows is largely and simply a representative overview of the meeting. Nearly all of the presentations—and a *white paper* with more in-depth information—are available for download from *pmm.nasa.gov/meetings/2015-gpm-applications-workshop/files*, and *go.usa.gov/3tygP*.

Opening Plenary Sessions

The meeting began with a plenary session that presented an overview of NASA's Applied Sciences Program and the GPM Mission, followed by a session that focused on science advances from TRMM to GPM. These were intended to (re)introduce GPM to the user community and present new scientific research that provided initial assessments of GPM data accuracy and performance.

Overview of NASA's Applied Sciences Program and the GPM Mission

Dalia Kirschbaum [NASA's Goddard Space Flight Center (GSFC)—*GPM Associate Deputy Project Scientist for Applications*] opened the meeting and stated that a goal of this gathering was to introduce precipitation data products—particularly new ones—to existing and potential users. She set the tone for this forward-looking, increasingly inclusive workshop with the focus on better understanding who is using TRMM and now GPM data and for what purposes as well as how we can expand this user community and improve data usability.

Lawrence Friedl [NASA Headquarters (HQ)—*Director of NASA's Applied Sciences Program*] gave an overview of the Applied Sciences Program, stressing the importance of connecting science and scientific research to actionable societal applications. New missions are being developed with applications in mind from the very beginning. He discussed the specific objectives of this

[1] To learn more about GPM see "GPM Core Observatory: Advancing Precipitation Measurements and Expanding Coverage" in the November–December 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 6**, pp. 4-11] and/or visit *pmm.nasa.gov/GPM*.
[2] The first meeting was summarized in "Measuring Rain for Society's Gain: GPM Applications Workshop" in the January–February 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 1**, pp. 26-34].

workshop from the NASA Applied Sciences perspective, charging the participants to provide feedback about how they are using GPM products, what is inhibiting them from more rapidly adopting such products, and who else should we involve as end-user communities as we grow the GPM applications program.

Ramesh Kakar [NASA HQ—*TRMM and GPM Program Scientist*] introduced GPM and gave a status update on the impressive implementation and results from TRMM, which at the time of the meeting had been passivated and was just about to reenter Earth's atmosphere. He emphasized that GPM can study precipitation in greater detail—and with greater accuracy—than TRMM. Kakar discussed the two GPM instruments (GMI and DPR) and gave more details about the constellation members. DPR provides a reference standard for GMI, which is then used to "tune" the other radiometers in the constellation—i.e., it improves the constellation's data accuracy. He then discussed some of the more interesting results from GPM's first year, introduced the data products, and discussed the wide range of applications for data from the GPM Mission.

Gail Skofronick–Jackson [GSFC—*GPM Project Scientist*] discussed the enhancements of the GPM Core Observatory compared to TRMM, including increased Earth coverage and the more advanced instruments onboard. She particularly emphasized the improvements to the radiometer, which she described as the "best calibrated precipitation radiometer in space." She then showed a table summarizing the differences between the GPM precipitation products (GMI, DPR, Combined GMI and DPR, and IMERG) and described a number of additional applications that use GPM data. Skofronick-Jackson ended with a summary of GPM ground-validation activities conducted around the world to validate retrievals from GPM.

Kinji Furukawa [JAXA—*Acting JAXA GPM Project Manager*] began by explaining how JAXA has partnered with NASA on both TRMM and GPM, and has provided instruments for other NASA Earth Observing System (EOS) missions. Furukawa shared more details about DPR, the instrument JAXA developed on GPM, which acquires data at two microwave frequencies (K_a and K_u) and produces three-dimensional profiles of precipitation (analogous to a CAT scan). DPR also provides important information on precipitation characteristics for GMI algorithms. Furukawa then proceeded to discuss Global Satellite Mapping of Precipitation (GSMaP), which is the multisatellite precipitation product produced by JAXA, providing hourly global rainfall maps in near-real time.

George Huffman [GSFC—*GPM Deputy Project Scientist, Chair of Multi-satellite Algorithm Team*] began his presentation discussing the evolution of precipitation data products. He showed the diverse, changing, uncoordinated set of precipitation-relevant input data that are part of the constellation, and showed how TRMM data products mapped onto GPM data products; he then described GPM data access. Huffman also fielded questions about the transition from the TRMM Multi-satellite Precipitation Analysis (TMPA) to IMERG and explained that the plan was to continue running TMPA through mid-2017, at which point the Precipitation Processing System (PPS) will provide a fully reprocessed IMERG dataset going back to the beginning of TRMM in 1998.

Science Advances: From TRMM to the GPM Era

TRMM laid the groundwork for precipitation missions generally, and set a high bar for follow-on work. This session addressed some of the ways in which GPM will continue that legacy and point to future science results.

Dave Randel [Colorado State University] described how the GPM algorithm process works to incorporate measurements from DPR and GMI for Level-1 and Level-2 products utilizing the Goddard Profiling Algorithm (GPROF). He described the development of the latest Bayesian version of GPROF 2014.

Joe Turk [NASA/Jet Propulsion Laboratory] addressed advances in understanding land-surface phenomena brought about largely by the combined use of radar and radiometer data—e.g., GMI and DPR. He noted that in the future there will be increased use of physical models for land emissivity, more realistic forward modeling of clouds and precipitation, and more efficient methods to couple land information into the retrieval techniques.

Misako Kachi [JAXA, Earth Observation Research Center (EORC)] covered GSMaP and GPM applications at JAXA, which include weather forecasting and monitoring; flood warning and prediction; and agriculture, industry, education, and public health. He also described GPM synergies with other JAXA missions.

Christa Peters–Lidard [GSFC—*Deputy Director of Hydrospheric and Biospheric Sciences*] focused on the idea of integrated hydrologic validation, which involves assessing the performance of satellite precipitation products using hydrologic and water resources applications and characterization of model and observation errors. She focused on synergies between GPM and the Soil Moisture Active Passive (SMAP) mission[3] in areas such as product evaluation, improving precipitation products, improving retrievals, joint retrievals, and coupled physics. She concluded by introducing several future missions that should each contribute key

[3] **EDITORS NOTE**: The SMAP radar halted transmissions on July 6, 2015; the radiometer, however, continues to collect science data.

hydrological data that will increase our understanding of the water cycle.

Panel Plenary Sessions

The remainder of the meeting concentrated on examples and discussion across a broad range of application areas. There were five panel plenary sessions that were set up to loosely align with elements of NASA's Applied Sciences program. These were:

- Weather Forecasting;
- Weather Communication;
- Water Resources, Food Security, and Agriculture;
- Public Health and Ecological Forecasting; and
- Disasters.

Weather Forecasting

Weather forecasting is a critical application of GPM data for many different numerical weather prediction models. Over time, resolution (temporal, radiometric, and spatial) of remotely sensed precipitation information has improved, which has helped to significantly advance modeling efforts.

Benjamin Ruston [Naval Research Laboratory (NRL), Ocean and Atmospheric Science and Technology Directorate] gave the keynote presentation, wherein he summarized numerical weather prediction (NWP) activities at NRL. Ruston explained that *ensemble modeling methods* (combining input from multiple models) are essential to really "get [weather forecasting] right," and that having multiple inputs also helps to produce a more accurate portrayal of the actual atmosphere. Advanced modeling efforts and data assimilation are making major contributions to these efforts.

Kevin Garrett [National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite Data and Information Service (NESDIS), Joint Center for Satellite Data Assimilation (JCSDA)] described preparations for incorporating GPM data into NWP models at NOAA, and showed an example of how a hurricane forecast track is improved when GMI data are assimilated vs. when GMI is not used—see **Figure 1**.

Brad Zavodsky [NASA's Marshall Space Flight Center (MSFC) Short-term Predication Research and Transition (SPoRT) Center] described how SpoRT works to transition unique NASA and NOAA observations and research capabilities to the operational weather forecasting community to improve short-term weather forecasts on regional and local scales. Zavodsky described how SPoRT works with users to identify problems and challenges throughout the modeling process and to develop solutions[4]. Forecasters can use SpoRT-generated products to supplement radar data in data-void regions over water and in parts of the western U.S.

Yasushi Suzuki [Japan Weather Association (JWA)] discussed satellite applications of weather services in Japan. Weather is "big business" in Japan. JWA (*tenki.jp*) is 1 of 62 private weather companies in Japan (with 9300 certified forecasters), and offers value-added products to the public. Suzuki discussed some of JWA's activities and their application to everyday public activities.

[4] To learn more about SPoRT, see "Transitioning Earth-observing Satellite Data to the Operational Community" in the May–June 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 3**, pp. 4-11].

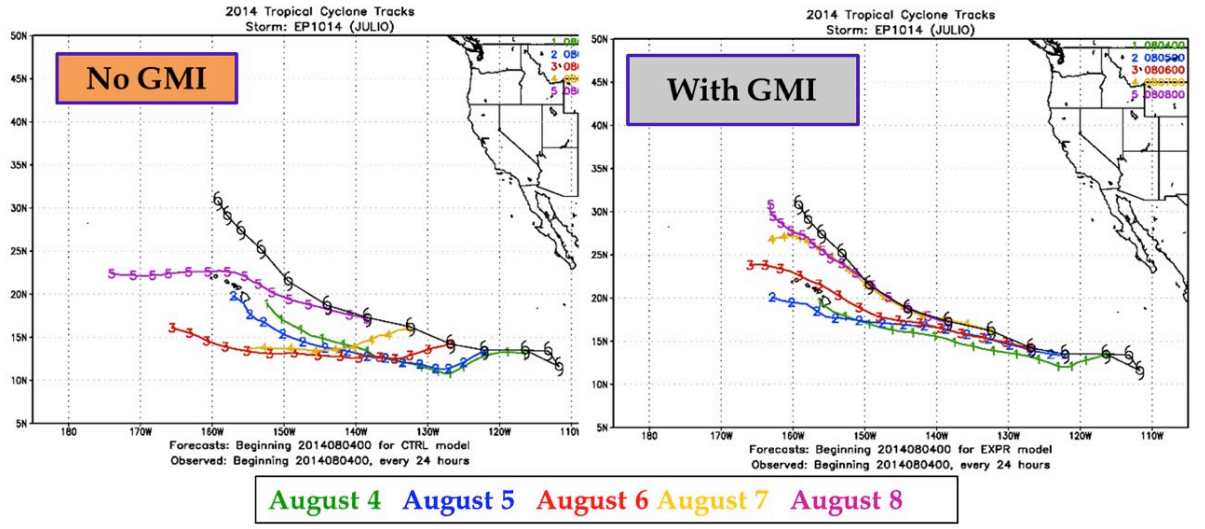

Figure 1. Forecast tracks for Hurricane Julio, which occurred off the coast of Mexico August 4-8, 2014. The various track lines indicate the forecast for each of the days the storm occurred. Shown are track forecasts made without assimilating GMI data [*left*] and with GMI data assimilated [*right*]. The results indicate that the forecasts better match the "true" forecast (black line) when GMI data are included in the modeling. **Image credit**: Kevin Garrett

Weather Forecasting Panel Discussion

After responding to a couple of questions specific to the technical details of their presentations, the panelists fielded questions on how observations from satellite sensors are integrated into NWP models. Specifically, all panelists responded to a question from **Dalia Kirschbaum** on the extent to which advanced GPM measurements improve NWP when assimilated. The panelists agreed that there are challenges to assimilating Level-1 and Level-2 data as well as incorporating DPR data—something that most NWP models have not yet implemented. The panelists stressed that there are efforts to make adjustments to microphysics in the NWP models using observational guidance. However, there is still no straightforward way to assimilate this detailed information. The panelists also explained that the integration of such data is model-dependent (e.g., global model clouds vs. radiative transfer clouds), citing that parameters must mesh with the selected model. Overall, the panelists seemed optimistic that incorporating GMI and DPR Level-1 and Level-2 data could ultimately improve the model forecasts. They also emphasized that validating forecasts using near-real-time products such as IMERG enables quick determination of bad vs. good observations—i.e., faster than the typical lag-time of 24-to-48 hours that most data sources would allow.

Weather Communication

In our increasingly connected, news-all-the-time world, useful information must be made available in a timely fashion, and presented as accurately as possible. This is particularly difficult across the wide range of potential recipients for this information. While a long-term activity, communicating the weather to constituent audiences has taken on even greater significance, as encapsulated in the presentations in this session. The consensus was that using mass media to get messages out is not only effective, but that it is possible to maintain a high science standard while at the same time making the information "consumable."

Todd Hutchinson [The Weather Company (TWC)] discussed the use of GPM and IMERG data at one of the world's largest private weather companies. TWC provides services to a wide variety of end-users and a broad spectrum of business and governmental agencies by generating compelling and useful products. There is a heavy emphasis on the use of satellite data.

Marshall Shepherd [University of Georgia—*via WebEx*], the host of *WxGeeks* (*www.weather.com/tv/shows/wx-geeks*) on The Weather Channel spoke next. His program is the first "Sunday morning talk show" dedicated to science, technology, engineering, and math (STEM)—with emphasis on weather and climate. Shepherd focused on the role the program plays as a communications tool for the science community. He provided information to show why science communication and outreach is essential, as there is a gap between the opinions of scientists and the general public.

Jason Samenow [The Capital Weather Gang] made similar observations. The Capital Weather Gang is part of the weather team (meteorologists and science writers) for *The Washington Post*. They place emphasis on reader engagement and communicating uncertainty. Based on his experience, Samenow provided some advice about effective communication, emphasizing timeliness, compelling visuals, succinctness, and comprehensible captions. Samenow ended with some information on how to engage with The Capital Weather Gang through various social media outlets—e.g., blogs, *Facebook*, *Twitter*.

Weather Communication Panel Discussion

These presentations emphasized the fact that it is essential for NASA to "find its voice," i.e., scientists need to speak out and use the media and social media to get their messages out to a wide audience. Scientists need to speak in a language and at a level that the general public can understand, which is not easy and requires training. One of the conclusions was that NASA needs to improve its social media presence, particularly when it comes to covering weather and climate, with a clearer and more direct strategy for bringing NASA data to the forefront of the national and international discussion. Underlying this is generation of clear, interesting, and timely visualizations of significant weather and climate information. **Gail Skofronick–Jackson** reminded everyone that, "communication is a two-way street." The panel concluded with the observation that all science and communication team members are accessible and are open to new ideas if there is something they feel would make a good news story.

Water Resources, Food Security, and Agriculture

The applications of GPM and related data products are clearly seen in how such data affect our understanding and use of water resources, the implications for food security, and agriculture, generally.

Gary Eilerts [U.S. Agency for International Development (USAID)] focused his keynote presentation on the increased incidences of drought and ongoing famine in some regions of the world. He described the

connections between the Famine Early Warning Systems Network (FEWS NET) and NASA. FEWS NET seeks to prevent famine and mitigate food insecurity by providing decision makers with information that is accurate, credible, timely, and actionable. Eilerts also introduced the concept of *food security mission creep*, where food security ends up dovetailing into a variety of different areas—e.g., food and nutrition security, chronic food insecurity, resilience and development in the most difficult places, water security, and unresolved conflicts.

Wade Crow [U.S. Department of Agriculture (USDA), Agricultural Research Lab] followed with a description of a global root-zone soil moisture data assimilation system designed so that the soil moisture and rainfall products mutually compensate for their random errors. He pointed out that the SMAP mission is now underway, and incorporating its data should lead to improvements in soil moisture retrievals. Crow also noted that establishing continuity between TRMM and GPM is essential, perhaps more so than with NWP applications.

Amy McNally [GSFC/University of Maryland] discussed joint NASA and USAID water security activities related to FEWS NET. Echoing Gary Eilerts' earlier comments, she stressed that food security is much more than agricultural monitoring, and provided several examples of how remotely sensed data products were applied to drought modeling activities. She noted that the IMERG product is likely to be an important source of additional information for near-real-time drought monitoring. However, longer-term analysis has to be done with predecessor rainfall products until IMERG has a consistent, long-term precipitation record from which to calculate anomalies and compare to historical patterns.

Curt Reynolds [USDA, Foreign Agricultural Service (FAS)] described how the FAS focuses primarily on USDA's overseas activities, including market development and information transfer, international trade agreements and negotiations, and collection and analysis of crop production and trade statistics. He described USDA's economic information system and economic intelligence system, which ties production data to price swings. He provided examples of how the FAS produce objective and accurate assessments of global agricultural production outlooks and conditions that impact global food security.

Water Resources, Food Security, and Agriculture Panel Discussion

One of the points made during the panel discussion was that rainfall data are worth more if you give them away. **John Haynes** [NASA Headquarters—*Program Manager for Health and Air Quality*] said that NASA tries to avoid buying data. For example, NASA has worked with countries in the Horn of Africa to make data freely available. The panel discussion also focused on how applications related to food security monitoring require a climatology, which requires having a multi-year dataset of key parameters like rainfall data. Therefore, reprocessing the IMERG and other GPM data products for continuity with TMPA data is of paramount importance in the area of food security.

Public Health and Ecological Forecasting

A clear application of GPM data comes in the areas of public health and ecological forecasting, where short-term observations must be used in conjunction with information on long-term trends in an effort to keep Earth's biological systems healthy—with particular emphasis on the human components.

Ben Zaitchik [John's Hopkins University] began his keynote presentation by pointing out that most applications in this area are highly mediated and often represent multiscale systems. For example, there are several factors that influence the transmission of malaria (namely, precipitation and temperature patterns), and climate is one of them. He noted that models have a strong empirical component and provide a consistent framework for which to compare and analyze data. Zaitchik discussed how data and models support the identification of breeding sites and prediction of malaria outbreaks, ultimately helping in the mitigation and elimination of the disease. Echoing conclusions from the earlier *Weather Forecasting* session, Zaitchik closed by explaining the importance of communication between data providers and end-users, pointing out that with accessibility comes risk of misinterpretation, and that data providers need to facilitate interpretation.

Molly Macauley[5] [Resources for the Future—*Vice President for Research*] addressed the value of information attributes. She discussed the economic benefits of using GPM data, explaining how spatial, spectral, and temporal domains can have a significant influence on public decisions and actions. She emphasized that there are tradeoffs between knowledge of the science and our ability to predict specific event frequency and severity with government or local response. Specifically, Macauley introduced a study that was able to define the tradeoffs between providing reliable warnings at specific lead times (in hours) before a storm and the benefit or cost of making that warning.

[5] Macauley gave a presentation during the 2013 workshop, which is summarized on page 31 of the report on the first GPM Applications Workshop, referenced earlier.

Anta Jutla [West Virginia University—*Assistant Professor of Civil and Environmental Engineering*] talked about the role of precipitation in creating environments for diarrheal diseases, through macroscale, microscale, and ambient hydroclimatological processes. The work he presented focuses on *macroscale processes*—those outside the pathogen and the person. Jutla provided several examples of how remotely sensed precipitation data from TRMM, in combination with other data, can be used to effectively model the spatial patterns and onset of these diseases. Future work will expand to modeling other diarrheal pathogens utilizing other Earth-observation data, including IMERG.

John Haynes [NASA Headquarters—*Program Manager for Health and Air Quality*] explained why health and air quality are connected under the auspices of NASA's Applied Sciences Program. The program supports the use of Earth observations in air quality management and public health, particularly regarding infectious disease and environmental health issues. He discussed global emerging diseases and new environmental threats that NASA is contributing data and models to monitor.

Public Health and Ecological Forecasting Panel Discussion

The panel fielded a number of questions from workshop participants about reducing latency times, the uncertainty of IMERG data, and restructuring data access. One of the advantages that the panelists agreed on was that the increased spatial and temporal resolution of IMERG relative to TMPA is highly valuable for their model inputs. They also stressed that having a standard satellite climatological tool would be very useful, emphasizing that often the absolute values of the measurements are not important, but rather the deviation from "normal" is what matters most. Another issue that the panel discussed is the communication of uncertainty.

Disasters

The topic of disasters spans a broad range of areas and response categories, ranging from NOAA making operational predications of the next tropical cyclone to international aid organizations using Earth-observation data and models derived from these data to provide timely, actionable information to a range of end users. This session outlined some of the applications and limitations of utilizing remotely sensed data across different organizations.

Frederic Zanetta [International Federation of Red Cross and Red Crescent Societies (IFRCS)] gave the keynote address in this session, which described how the IFRCS uses Earth observations at various stages in the disaster cycle: relief, recovery, response, preparedness, and mitigation. He noted that Earth observations are used to cross-check funding mechanisms for imminent crises and response requests, particularly for small- and mid-scale disasters that are not always covered by the media. Zanetta highlighted what was now a common thread across the panel plenaries; he explained that one of the biggest limitations to making use of NASA data is communication. That is to say: end users generally do not "speak science," and therefore a commitment is required of those who support transformation of observations into understandable and directly usable information.

Sezin Tokar [USAID, Office of U.S. Foreign Disaster Assistance (OFDA)] described disaster risk-reduction activities at USAID, explaining that the objectives are to save lives, alleviate suffering, and reduce the social and economic impact of disasters. A focus of her presentation was OFDA's Flash Flood Guidance System (FFGS), which provides information on flash floods across different regions. The system utilizes satellite precipitation estimates, forecast data, snowmelt prediction, and other variables to generate flash flood forecasts.

Chris Chiesa[6] [Pacific Disaster Center (PDC)] gave a background on the PDC and described how they seek to build bridges between the science and technical community and decision makers. He described PDC's flagship product, the DisasterAWARE Platform (with over 1.5 million users, worldwide), and a mobile version, the Disaster Alert App, that provides information on ongoing disasters in real-time. Chiesa showed several examples of the program in action, including TMPA precipitation maps that explained the antecedent precipitation over Nepal following the Gorkha earthquake in April 2015; maps of track forecasts, sea surface temperature, and population density, which help determine what populated areas are in harm's way; and flood monitoring in the Central U.S. in May 2015.

James Kurz [Mercy Corps, Microinsurance Catastrophe Risk Organisation (MiCRO)] presented an overview of MiCRO, a specialty insurer founded in 2011 after the Haiti earthquake. The focus of this group is on ameliorating the monetary effects of disasters. MiCRO focuses on natural catastrophes and impacts to low-income segments of the population in a growing number of Western Hemisphere countries, with an eye toward providing a "safety net" for vulnerable countries and communities. Kurz illustrated the difference insurance can make in helping to expedite recovery from disasters, comparing the recovery from the earthquake in

[6] Chiesa gave a keynote presentation during the 2013 workshop, which is summarized on page 30 of the report on the first GPM Applications Workshop, referenced earlier.

Haiti (January 2010) to that of the earthquake in Chile (February 2010)—see **Figure 2**. Lessons learned from MiCRO's endeavors include the importance of developing a value-added program and the critical importance of an innovative and enabling environment.

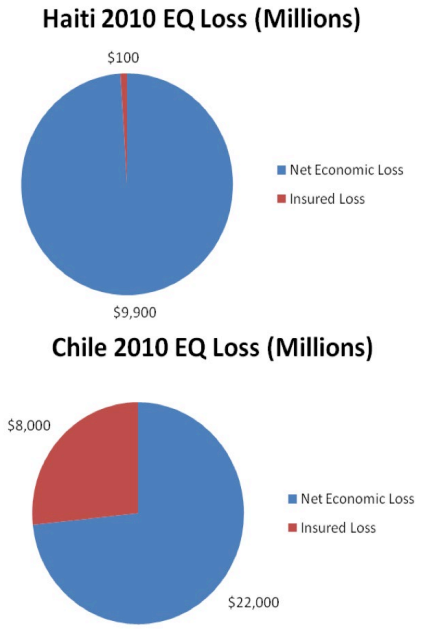

Figure 2. This figure illustrates the difference insurance can make in recovering from disaster. Both Haiti and Chile experienced major earthquakes in 2010. In Haiti only 1% of all economic losses were insured, while in Chile nearly 37% were insured. Increased (re)insurance penetration contributed to the relative speed and robustness of Chile's economic recovery vs. Haiti's. **Image credit:** James Kurz

Disasters Panel Discussion

One question that was asked during the discussion was: *How receptive are people to using satellite data?* There is still a good deal of suspicion surrounding such data. Many at the meeting understood both sides and could clearly communicate the linkages between satellites and applications—but those people are relatively rare compared to the diverse potential user base. Another issue that came up was the increasing demand to have some sort of disaster response capability at NASA. Recent incidents such as the 2010 *Deepwater Horizon* oil spill into the Gulf of Mexico and the 2015 Gorkha earthquake in Nepal highlight the need to develop a more formal plan. **David Green** [NASA HQ—*Program Manager for Disasters*] responded that NASA is in the process of preparing a plan that would involve all of its Field Centers in disaster response and link to most, if not all, of the organizations represented at the workshop, as well as many more.

Breakout Sessions

The four breakout sessions corresponded to the topics covered in panel plenaries. Weather forecasting and communication were combined into one breakout group. The moderators of the breakout sessions were charged with answering several key questions:

- What GPM data and products are you and the community currently using?
- How has the transition from TRMM to GPM taken place? What have been the limitations and benefits, or why haven't you transitioned if you are still using TRMM data?
- Are there additional feasible data products from GPM datasets that would be helpful in your science or applications tasks?
- What are the biggest impediments limiting your use of GPM satellite data and products?
- What are the discipline or focus-area science questions or application challenges that can be addressed with GPM data?
- Who are your key partners or end-user organizations that use NASA satellite data?
- Who are additional potential users that the community should reach out to?
- Looking ahead, what are the challenges and opportunities that you would like to see addressed that could impact your community? Are there some key questions that have not yet or not fully been addressed that we should focus on for the applications user communities?

All groups consistently stressed the need for an extended data record and climatology from which to evaluate anomalies and validate their models. Many of the end users stated that they were less likely to transition to using the IMERG product until a reprocessing takes place that will develop a consistent, long-term baseline from IMERG. Another point of discussion was the concept of the nexus between food, water, and security, coupling different models for improved situational awareness. This will help both for disasters as well as outlining transboundary water issues, vulnerable areas, etc. A final point from the breakouts was the need for clear and reliable quality control metrics and continuity of measurements for operational models.

Workshop Summary

With GPM now a year-and-a-half into its planned three-year mission lifetime, this two-day workshop provided an excellent opportunity to promote GPM product applications and to hear feedback from the community. Presentations, posters, and discussions showcased the capabilities of GPM products and gave attendees the opportunity to explore research and applications interests. This workshop also provided the framework

Training Session on the Use of GPM Data

On June 11, the day after the GPM Applications Workshop, there were two, half-day training sessions held at the Earth System Science Interdisciplinary Center at the University of Maryland, College Park. There were 27 participants from a number of organizations. During these four-hour sessions, **Amita Mehta** [GSFC/JCET] guided participants through a more in-depth look at GPM products and data access. In the first two hours, she provided an overview of GPM data products, and the many different sites from which to access GPM data. Mehta demonstrated spatial and temporal selection and extraction of Level-2 and Level-3 GPM data and visualization capabilities provided by these sites. In addition, she outlined the procedures to download GPM data in various formats (e.g., HDF5, NetCDF, and GeoTIFF) and import them in to *ArcGIS* for further applications.

In the remaining time, Mehta guided participants through hands-on tutorials for access, analysis, visualization, and download of the GPM data from the Precipitation Processing System - STORM (*storm.pps.eosdis.nasa.gov/storm*) and Giovanni (*giovanni.gsfc.nasa.gov/giovanni*) sites. She provided two scenarios where participants learned to download half-hourly and monthly IMERG products, and orbital swath data from GPM Microwave Imager; visualize the precipitation maps, time sequences, and rain-rate histograms using specific parameters; and understand the options for how they could replicate this information again for their own data applications.

for better understanding user needs and outlining challenges to data access and usage that will be used to improve the utility of data products and information with the community. There were four main themes that arose in the workshop, listed here with some rationale for their inclusion:

- There is a clear need for a long-term, consistent precipitation record. Many users will not transition from TRMM to GPM products until that record or some "bridging" dataset exists.
- Spatial and temporal resolution vary by application. Having an "early," "late," and "final" IMERG product is appreciated by the user community.
- Data files, formats, and access procedures are not clear. Among other impediments, users have difficulty deciding which product to use, how to understand errors, where to access data, and more. Additional work needs to be done to better cater to these different levels of experience in the community.
- Continuity of precipitation measurements is now an expectation of the community. The end-user community assumes that NASA will provide precipitation measurements both continuously and with global homogeneity. For best data product development, user feedback to NASA and input to other interested parties is needed, and eagerly solicited.

This workshop enabled a broad range of discussions, networking, trainings, and valuable feedback to the GPM Program, all of which the team is actively working to create into action items for the coming years. Overall, the workshop provided an excellent opportunity for dialogue between users and scientists and managers about how the GPM applications program can grow to better address the user community's needs.

In addition to panel plenaries and breakout sessions described herein, there were two other opportunities for attendees to engage with GPM data providers and share research during the meeting. A *Meet the Developer* brownbag lunch took place the first day with about 40 people participating. **George Huffman** and **Owen Kelley** [GSFC/George Mason University] gave some brief opening remarks about GPM data and IMERG that led into an extended question and answer session during which end users could ask more in depth questions about GPM data, access, and quality. There was also a *Poster Session* held after the Weather Communication panel (at the end of the first day of the workshop). About 15 different end users and algorithm developers presented their research, allowing for one-on-one interaction and more detailed discussions about current projects and activities. These items are discussed in more detail in the white paper referenced above.

Acknowledgments: The authors wish to thank the following individuals who took notes on one or more of the individual sessions that were most helpful in creating this article: **Heather Hanson, Dorian Janney**, **Amita Mehta**, **Kasha Patel**, **Jacob Reed**, and **Kristen Weaver**—all of whom are at GSFC. ■

meeting summaries

Continuity Assured: The First Postlaunch MODIS/VIIRS Science Team Meeting Summary

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Introduction

The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Earth Observing System (EOS) Terra and Aqua satellites and Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite have been collecting data about Earth's atmosphere, land, and ocean since they successfully launched in 1999, 2002, and 2011, respectively. On May 18-22, 2015, the MODIS and VIIRS science teams met jointly at the Sheraton Hotel in Silver Spring, MD for a detailed discussion on the continuity of data among the instruments.

NASA's goal is to provide data records that bridge the EOS, Suomi NPP, and subsequent Joint Polar Satellite System (JPSS[1]) missions that are suitable for climate research and societal applications. Accordingly, the theme of the meeting was to insure continuity of MODIS data products from NASA EOS missions into the JPSS era. This is also a major goal of the science teams in general. To help achieve this goal, NASA has funded the development of a suite of Suomi NPP algorithms. This meeting was a unique encounter, since it provided the opportunity for the teams to review how well MODIS algorithms are producing VIIRS data products. Such a review is timely, since VIIRS has been acquiring data for several years, and these data are presently going through extensive validation.

The meeting was organized to highlight the three Earth science disciplines: atmosphere, land, and ocean. Investigators gave presentations from each discipline during the plenary session. There was also a special breakout session for MODIS and VIIRS instrument calibration on the first day. The second day opened with a plenary session consisting of a series of programmatic presentations from NASA Headquarters (HQ) and NASA's Goddard Space Flight Center (GSFC) representatives, followed by the plenary presentations from each discipline. The discipline breakout sessions were held nearly concurrent with the three-and-a-half days of plenary talks. The meeting ended with summaries from the breakout sessions and then concluded with a presentation from HQ on the future of MODIS and VIIRS and the science teams' challenges to fulfill the needs of the science and applications users. The presentations for the entire meeting are available at *modis.gsfc.nasa.gov/sci_team/meetings/201505.*

[1] JPSS-1 is scheduled to launch no earlier than late 2016 with subsequent launches into the next decade. Suomi NPP is a "bridge mission" between EOS (Terra and Aqua) and JPSS; it carries essentially the same instruments that will fly on JPSS-1 and provides continuity with EOS until JPSS-1 is operational and an opportunity to intercompare JPSS instruments with the comparable instrument(s) on EOS platforms, e.g., MODIS to VIIRS.

Opening Plenary

Michael King [University of Colorado—*MODIS Science Team Leader* and *Former EOS Senior Project Scientist*] opened the meeting, welcoming participants and presenting the agenda. He also served as emcee for the opening plenary session.

Michael Freilich [NASA HQ—*Director of the Earth Science Division (ESD)*] began with an overview of the FY16 President's Budget Request, followed by the status of NASA's Earth Science program. As of this writing, Congress continues debate on the President's request. At that time, there was no consensus in either the House's or the Senate's Appropriations and Authorization Committees. If Congress' proposed budget holds, NASA Earth Science program will be reduced. Better news came with an overview of Earth science launch successes. Freilich noted that three major missions have been placed into orbit and two instruments installed on the International Space Station (ISS) since the beginning of 2014, and that NASA is scheduling eleven more missions for launch over the next seven years. He then showed highlights from the recently launched missions. Freilich concluded by summarizing upcoming mission commitments, and most significantly the authorization for Landsat 9 and future Landsat investments.

Paula Bontempti [NASA HQ—*Program Manager and Scientist for Ecology, Carbon Cycle, Biogeochemistry, Terra, Aqua, and the Suomi NPP Science Team*] provided an extensive overview of the HQ perspective on MODIS and VIIRS science team priorities. She outlined the timeline for the Terra and Aqua recompetition and the expected budget. Bontempi also noted that proposed efforts in response to the Senior Review and Research Opportunities in Space and Earth Sciences (ROSES) competitions should be clearly defined, and further emphasized that proposers need to concisely identify the accuracy of their data products and their relevance to science and societal benefits. Finally, Bontempi reviewed the status of the Suomi NPP VIIRS Science Team selection. The selection focused on two requirements: science community participation in new scientific activities, practical application, and climate research; and the establishment of Science Investigator-led Processing Systems (SIPS[2]) to produce NASA Suomi NPP standard and research science data products.

[2] A SIPS will be established for each of the VIIRS science disciplines: Atmospheres, Land, and Oceans.

Jack Xiong [GSFC—*Technical Lead for the MODIS and VIIRS Characterization*] presented a detailed summary of the Calibration breakout session on the Terra and Aqua MODIS and Suomi NPP VIIRS instruments' status that included orbit operation, calibration, and performance. Overall performance of all three instruments in orbit remains nominal. He noted that calibration modes for VIIRS would be the same as for MODIS. More specifically for MODIS, Xiong showed that time-dependent plots of several instrument parameters are either stable or their changes are successfully being tracked. He noted that the calibration team will focus its future efforts on addressing challenges resulting from instrument aging. Xiong also reported that processing and reprocessing for data Collections 5 and 6 are on schedule.

Moving on to VIIRS, Xiong noted that on-orbit function and calibration have been nominal, with only temporary minor disruptions to normal operations. The initial large degradation of mirror throughput in the near- and short-wave infrared regions on VIIRS has leveled off and the sensor continues to meet the design requirements. Xiong concluded with a report on the JPSS-1 VIIRS prelaunch test and calibration. Test personnel demonstrated key instrument performance successes in ambient and thermal vacuum environments. The instrument was integrated onto the spacecraft at Ball Aerospace & Technologies Corp., in Boulder, CO, and has successfully completed its initial ambient testing with performance that is comparable to or better than that for the Suomi NPP VIIRS. Comprehensive testing of the spacecraft's in-flight configuration with all instruments mounted is expected in early 2016.

Claire Parkinson [GSFC—*Aqua Project Scientist*], speaking for herself and the Terra Project Scientist Kurt Thome, provided an overview of the status of and schedule for the Terra and Aqua Senior Reviews. Printed proposals were submitted in early March and the review panel met in late April. Parkinson provided an overview of the two missions and their instruments' status (with an emphasis on MODIS), and announced that Terra and Aqua were capable of providing data at least through 2025 and 2021, respectively. In response to one of the panel's general questions concerning the remaining priorities for the missions, Parkinson stated that maintaining a high-quality, end-to-end data stream would be the top-level effort. Many of the Aqua and Terra instruments continue to transmit high-quality data, despite being well beyond their design lifespans.

Fred Patt [GSFC/SAIC—*Project Manager*] followed up with a presentation of VIIRS Level-1B algorithm and software development. The main feature is the requirement to process the VIIRS Level-1 data starting from the EOS Data and Operation System (EDOS) Level-0 data feed, bypassing the National Oceanic and Atmospheric Administration's (NOAA's) Raw Data Record (RDR) product. Past RDR products will be converted to Level-0 (EDOS) format. Subsequent processing to Level-1a will be archived in the SIPS in order to produce higher-level data products; the Ocean SIPS has successfully tested this conversion. This will result in modular, well-documented, efficient, robust, portable software that NASA owns and maintains, and will enable straightforward implementation of instrument calibration equations and support for calibration updates. NASA will also develop and maintain product formats that serve the largest possible user community.

Atmosphere Algorithms and Science

The atmosphere discipline discussion focused on the meeting's main theme of assuring and maintaining continuity from MODIS to VIIRS. Presenters talked about cloud masks, cloud properties, total precipitable water vapor, and aerosols. Since the last MODIS Science Team meeting in April 2014[3], the SIPS completed Collection 6 reprocessing for the Level-3 (L3) algorithm, and the L2/L3 products for both Terra-MODIS and Aqua-MODIS. Collection 6 user guides have been released for L2 cloud optical properties and cloud mask, and L3. Updated instructive webinars can be found at *modis-atmos.gsfc.nasa.gov/products_C006update.html*.

Cloud Characteristics

Quantifying the presence of global cloudiness remains a key issue for determining both Earth's radiative balance and successful retrievals of other atmospheric parameters—since clouds act as a contaminant to most surface retrieval algorithms. The cloud product suite will leverage both imager (VIIRS/MODIS) and sounder (CrIS/AIRS[4]) capabilities, because of the absence of key absorbing channels in VIIRS. The cloud investigators considered several approaches for linking the imager and sounder instruments. Cloud masking is the major tool for dealing with cloud contamination. One investigator described efforts to model the MODIS-VIIRS Cloud Mask (MVCM) after the MODIS Cloud Mask (*MOD35*). This remains a "work in progress," but is already an improvement over the MODIS Collection 6—see **Figure 1**. MVCM applied to MODIS and VIIRS has been validated against data from CALIPSO[5] with reasonable agreement. However, the algorithm needs more work for polar and snow-covered regions.

One of the breakout session presentations showed how marine boundary layer cloud top heights (CTH) can be derived by combining information from multiple sources: MODIS, CALIPSO, and COSMIC[6] Global

[3] This meeting was summarized in the September–October 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 5**, pp. 20-22].

[4] CrIS/AIRS stands for Cross-track Infrared Sounder/Atmospheric Infrared Sounder, both onboard Suomi NPP.

[5] CALIPSO stands for Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations. The measurements are actually from Cloud-Aerosol Lidar with Orthogonal Projection (CALIOP) onboard CALIPSO.

[6] COSMIC stands for Constellation Observing System for Meteorology, Ionosphere, and Climate.

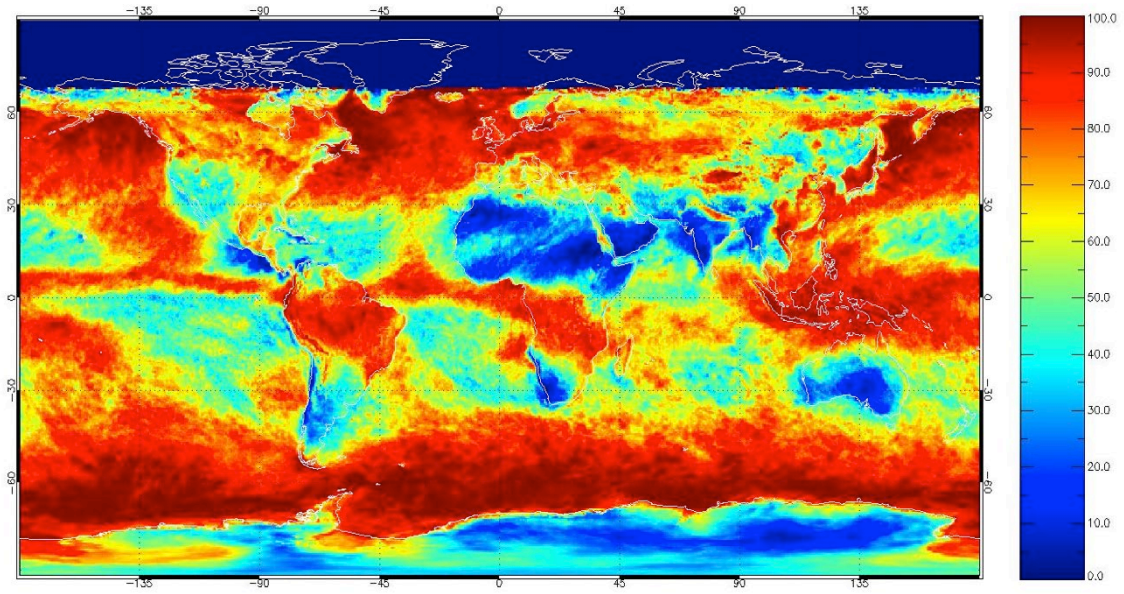

Figure 1. This map shows MVCM for January 2013. The MVCM employs the same algorithm as MODIS (MOD35) where possible, and ingests similar L1b bands for VIIRS and MODIS using similar ancillary data. It contains confidence of clear sky (Q) values and has similar output as MODIS (48 bits/pixel). **Image credit**: Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin - Madison.

Positioning System–Radio Occultation (GPS-RO) data over subtropical Eastern Oceans. MODIS cloud top temperature (CTT) along with sea surface temperature (SST) can be used to derive the CTH. CALIPSO CTH climatology compares well with COSMIC with some exceptions. CALIPSO and GPS-RO offer independent CTH measurements and, where applicable, will be used to verify and improve the MODIS CTH retrieval.

Total Precipitable Water

There was a discussion of the MODIS Clear-sky Infrared Total Precipitable Water (TPW) vapor product and its continuity with VIIRS and CrIS. TPW is important to determining Earth's radiation balance, precipitation intensity, and distribution. The goal of this study was to process data from the High-Resolution Infrared Radiation Sounder (HIRS), MODIS, and VIIRS with the same algorithm to create a TPW record that can reveal trends over a period of more than four decades. Seasonal TPW cycles are in good agreement (i.e., based on combinations of data from MODIS, HIRS, and the NASA Water Vapor Product), in areas where they overlap—except in the tropics. A TPW decrease in 2008 and 2012 is evident in several datasets: Aqua-MODIS, HIRS, and the NASA Water Vapor Project (NVAP). Such decreases in TPW are consistent with tropical La Niña events. The results indicate a possible increase in tropical TPW in 2015.

For VIIRS, the *split window algorithm*[7] enables 750-m (~2461-ft)-resolution TPW maps with some ability to depict moisture gradients, although very wet and very dry conditions are not captured well. Over land, the retrievals require careful attention to the surface emissivity, sea/land boundaries, and clear determination of brightness temperatures. Combining VIIRS data with output from the NOAA Unique CrIS/ATMS Processing System (NUCAPS) shows promise for continuing the TPW records established by HIRS and MODIS.

Aerosol Characteristics

This session continued to emphasize the meeting's theme of maintaining data product continuity. One of several aerosol algorithms is the *Dark-Target* (DT) algorithm that derives aerosol properties over land and ocean. The Collection 6 DT algorithm has been successfully applied to MODIS on Terra and Aqua with good agreement, and more recently to VIIRS. Although improved over Collection 5, Collection 6 trends derived from Terra and Aqua have offsets that diverge by a small amount—but differently over land and ocean. For VIIRS, a DT MODIS-like algorithm has been applied and compared globally with MODIS. Overall, aerosol optical depth (AOD) fields from each instrument are similar, but differences remain.

An alternate algorithm to the DT algorithm is the *Deep Blue* algorithm that also provides useful information about aerosol properties over bright, reflecting land surfaces. The investigators are updating the algorithm using Collection 6 and testing it on VIIRS data. Improvements are underway to enable better spatial coverage and retrieval accuracy compared to Collection 5. Validation using Aerosol Robotic Network (AERONET) measurements is underway. Because it has been in orbit three years longer and has experienced greater sensor degradation, MODIS-Terra performance is a little poorer than MODIS-Aqua. The VIIRS Deep

[7] The *split window algorithm* uses two differentially absorbing channels near 11 µm to remove the effects of atmospheric absorption to better estimate the land surface temperature. Since water vapor is the primary absorber in this wavelength range, split window measurements can produce TPW as well.

Blue product has similar quality to MODIS. Future work will include AOD retrievals over clouds and the determination of aerosol plume height using other instruments in the A-Train constellation of satellites.

Converting satellite measurements of AOD to Particulate Matter smaller than 2.5 μm in size ($PM_{2.5}$) is a priority area of research because of connections to human health[8]. Accurate conversions to $PM_{2.5}$ have several challenges, as the process is nonlinear and has several unknowns, including the aerosol vertical distribution, particle size distribution, and composition. Sampling issues and cloudy conditions during acquisitions further compound this problem. A novel approach employs an ensemble of satellite measurements and models. The benefit would be to fill in $PM_{2.5}$ data where there are no ground observations by combining AOD data from several satellites with a range of air-quality forecast and research models. The user interface to access this product would be through the Remote Sensing Information Gateway (RSIG) operated by the U.S. Environmental Protection Agency.

Establishing a NASA VIIRS Suomi NPP Atmosphere SIPS is a crucial component of maintaining continuity and delivery of climate quality datasets. The SIPS will have the capability for processing, reprocessing, and generally assessing Suomi NPP VIIRS Atmosphere products. It will process Level-0 data to Level-1, Level-2, and global gridded Level-3 atmosphere products using scientific algorithm software from the Suomi NPP Atmosphere Discipline Group. For the user, the Atmosphere SIPS will deliver all data products along with scientific algorithm software, associated metadata, and documentation to the Land and Atmosphere Archive and Distribution System (LAADS). For the near-real-time (NRT) user, the SIPS will access NRT algorithms for selected products, process, and deliver these products within three hours for distribution through the Land, Atmosphere Near real-time Capability for EOS (LANCE) system.

Land Algorithm and Science

The Land session began with a brief history of land measurements, beginning with the NOAA Advanced Very High Resolution Radiometer (AVHRR) onboard the series of Polar Orbiting Environmental Satellites, beginning in 1982. This was followed by MODIS onboard Terra in 1999 and Aqua in 2002, and then by VIIRS in 2011 onboard Suomi NPP. European missions such as French SPOT[9] and the upcoming launch of ESA's Sentinel-3 (2016) will compliment these missions. Looking to the future, the technical discussion dealt with actions needed to maintain data quality, such as geolocation, calibration, cloud screening, and atmospheric and surface reflectance correction issues.

Surface Properties

Most Land Surface algorithms—including their errors—are mature and well documented as they were refined for MODIS and tested on VIIRS; this is particularly true for surface reflectance. Support has been provided by using AERONET measurements to validate the aerosol component of the atmospheric correction. However, the Land Team needs to refine cloud and cloud shadow mask protocols. Extensive testing is underway to compare MODIS and VIIRS products important for producing surface products such as the bidirectional reflectance distribution function (BRDF), White-sky Surface Albedo, and Nadir BRDF-Adjusted Reflectance. Agreement was very good between the two instruments across the visible to the near-infrared spectral regions.

The transition of snow cover and sea ice algorithms from MODIS to VIIRS has gone well, paving the way for the development of Climate Data Records (CDRs) for these parameters. The snow cover product, now called the normalized difference snow index (NDSI), will include corrections for surface temperature and unaccounted-for surface reflectance conditions. Investigators used the MODIS snow products in the Satellite Snow Products Intercomparison and Evaluation Exercise (SnowPEX)—*calvalportal.ceos.org/projects/snowpex*—that was conducted by an international team. VIIRS Ice Surface Temperature and Ice Surface Extent products are under development. Preliminary results for the Ice Surface Temperature from validation field campaigns are favorable; the VIIRS Ice Extent product will be based on the MODIS algorithm.

Land Surface Temperature and Emissivity (LST&E) are key products derived from MODIS and VIIRS because of their use in water management, deforestation, and land-use applications, and the impacts of these on climate. The LST&E retrieval now employs a view-angle-dependent split-window algorithm that corrects for atmospheric and emissivity effects for various land-cover types. LST&E is also used as an input variable for other MODIS atmospheric and land products—e.g., aerosol, land-cover, and net primary productivity. The MODIS algorithm is undergoing modifications and improvements as it is applied to VIIRS in order improve accuracy, particularly over regions where the surface changes rapidly.

MODIS and VIIRS Land Surface products require corrections for both aerosols and clouds. The Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm simultaneously retrieves

[8] $PM_{2.5}$ is one of six criteria pollutants identified by the Clean Air Act and monitored by the U.S. Environmental Protection Agency.
[9] SPOT stands for Satellite Pour l'Observation de la Terre.

aerosol optical thickness (AOT[10]) and surface bidirectional reflection factor (BRF) using a time series of MODIS measurements. One presentation detailed an effort to update MAIAC to a full complete physical model of atmosphere–surface radiative transfer, which features a spectral regression coefficient (SRC) for aerosols and includes synergy among water vapor, cloud mask, aerosols types, and atmospheric correction. AERONET comparisons show a clear improvement of MAIAC-derived MODIS AOT.

The final presentation in this session described the status of the VIIRS Nighttime Lights algorithm that uses the day-night band (DNB). The VIIRS DNB measurements are the follow-on to the U.S. Air Force Defense Meteorological Satellite Program's Operational Linescan System (OLS) that has been collecting global low-light images since 1976. The VIIRS DNB measurements are vastly superior to those made by OLS because the DNB has better spatial resolution and dynamic range, and an onboard calibration source. The latest refinement of the DNB measurements is the development of Nighttime Lights Composite that serves as a baseline of persistent light sources. The present objective is to produce monthly cloud-free and no-moon nighttime light composites that are then upgraded to Stable Lights Composites. The upgraded algorithm will also employ a comprehensive radiative transfer model for atmospheric correction.

Vegetation and Productivity

The opening presentation in this session provided an overview of the vegetation index as a tool for phenology research and applications. Continuity of data is vital when it comes to studying the various vegetative cycles and how climate change affects these cycles. The presentation revealed the 34-year record of AVHRR, MODIS, and VIIRS measurements, assessing how they compare and possible improvements with VIIRS' advanced capability. Detailed comparisons showed some systematic difference between the sensors. For the normalized difference vegetation index (NDVI), the instruments agree to better than 10% where their data overlap over desert regions for the period 1980 to 2015. Correlations for the enhanced vegetation index (EVI), for MODIS and VIIRS, and EVI-2, which is used to extend the dataset back in time to include AVHRR, were very good for the four instruments. Challenges to maintain and further improve the index data include cloud masking, dynamic compositing, improved BRDF corrections, and better gap filling.

The next presentation dealt with an assessment of gross primary production (GPP) and net primary production (NPP) data from AVHRR and MODIS. Global trends in production are difficult to quantify because of geographic variability. AVHRR data from 1982 through 1999 indicated a global increase in NPP, but since then productivity seems to have declined. New data from MODIS now suggest an increase in NPP starting in 2005. A user can estimate global terrestrial evapotranspiration (ET) from the land surface from satellite data, and then calculate regional water and energy balance and soil water status. These data are key inputs to a variety of water resource management and land use applications. There is also a relationship between GPP and ET, where ET data can refine estimates of GPP for certain ecosystems. **Figure 2** is a global map of ET for 2000 to 2010.

The leaf area index (LAI) and fraction of absorbed photosynthetically active radiation (FPAR) are key biophysical variables fundamental to a range of ecosystem processes, e.g., GPP, ET, and net energy exchange. MODIS and VIIRS provide global measurements of LAI and FPAR with sufficient coverage to support regional- to global-scale modeling and monitoring efforts. An overview of the data processing and validation of these

[10] **EDITORS NOTE**: The equivalent terms Aerosol Optical Depth (AOD) and Aerosol Optical Thickness (AOT) are used interchangeably in this report. The author used whichever term the presenter used.

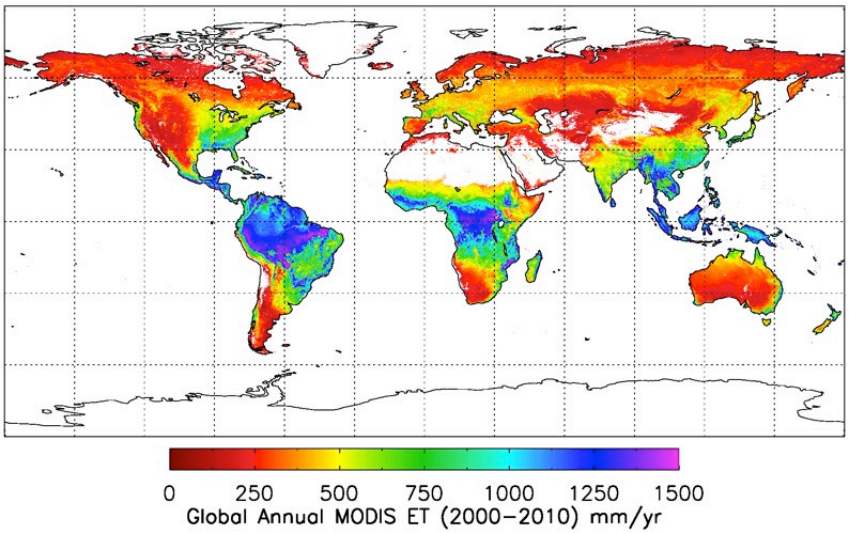

Figure 2. This map shows global annual 1-km (~0.6-mi) evapotranspiration (ET) from 2000 to 2010. ET is calculated using the *MOD16* algorithm from several measurements that include albedo, leaf area index (LAI), and fraction of photosynthetically active radiation (FPAR), with downward solar radiation (Rs), air temperature (Ta) and actual vapor pressure deficit. The global average MODIS ET over vegetated land surface is 568.7 ± 358.2 mm/yr. **Image credit**: Numerical Terradynamic Simulation Group College of Forestry and Conservation, University of Montana

products included both MODIS (Collection 6) and VIIRS (Collection 1.1), with comparisons with previous Collections. There was also an intercomparison of the latest version of MODIS with that of VIIRS. Results showed good agreement for MODIS between Collections 6 and 5. Collection 6 agrees better with *in situ* measurements for both LAI and FPAR, whereas VIIRS tends to overestimate both LAI and FPAR. Plans are to update VIIRS lookup tables, employ MAIAC, and continue validation field campaigns.

Maps of vegetation continuous fields (VCF) reveal changes in land use and human impact on naturally forested ecosystems. The VCF Version 5.1 improvements to all three layers (i.e., tree cover, non-tree vegetation, and bare) have led to further improvements at high latitudes. One of the presentations summarized these improvements, provided a series of global maps for each layer, and showed examples of acceleration and deceleration of net forest loss for the humid tropics between 1990 and 2000 and between 2000 and 2010. Net forest loss occurred in most of the humid tropics, with the most loss in Southeast Asia. Current activities include evaluating Collection 6 on all VCF products, composting refinements, validation, and then applying the algorithm to VIIRS measurements.

Discussion on Land Products continued with an update of the Active Fire and Burned Area data products. The Burned Area algorithm detects deposits of charcoal and ash, removal of vegetation, and alteration of the vegetation structure. Application of algorithms for VIIRS Active Fire products are on track, and the fire user community is seeing benefits. Intercomparison with the MODIS fire product and initial validation results indicate good overall performance. Data production personnel are implementing improved atmospheric corrections for MODIS Collection 6 and VIIRS; they have also ported the latest science algorithm to NOAA for operational use. Based on use of the Direct Broadcast Monthly Burned Area product algorithm, comparisons between MODIS and VIIRS Burned Area products look good.

Ocean Algorithms and Science

NASA's Ocean Biology Processing Group (OBPG) has supported the collection, processing, calibration, validation, archive, and distribution of ocean-related products from several NASA research and operational missions since 1996. The ocean product algorithms are predominantly sensor-independent, but they require specific adjustments to insure accuracy and continuity. Twelve MODIS product algorithms are being modified by adjustments for sensor specific spectral response. The following discussion describes the status of the transition of some of the algorithms to VIIRS ocean data products.

Ocean Color

Remote Sensing Reflectance (Rrs) is the fundamental remotely sensed quantity from which most ocean color products are derived, e.g., chlorophyll, particulate organic and inorganic carbon, and inherent optical properties (IOP[11]). The Ocean Color SIPS team is reprocessing historical data from multiple instruments, adopting modern data formats and standards in order to improve data interoperability. The reprocessing will include calibration updates and validation results for each instrument, and incorporate the latest algorithm updates. The MODIS algorithm team has implemented the retrieval algorithm for Rrs and chlorophyll to VIIRS. The VIIRS Rrs temporal stability has improved following an extensive recalibration effort, and the range of variability is now consistent with historical norms. MODIS-Aqua temporal variability in the blue spectral region has increased since 2011, with a large departure in all bands in 2014. The investigators are addressing these issues. MODIS-Aqua and VIIRS Rrs and derived chlorophyll are comparable in magnitude and spatial distribution with good temporal consistency, and show a similar level of agreement with *in situ* validation.

The amount of *coccolithophore phytoplankton*[12] can determine the ocean albedo and how much sunlight is reflected back to space. MODIS measurements from Aqua of particulate inorganic carbon (PIC)—otherwise known as calcium carbonate—can be used to determine coccolithophore bloom seasonal and long-term phenology. These measurements demonstrate the seasonality of PIC and its annual reoccurrences over its data period, as blooms peak in the summer in both hemispheres. Comparing PIC and chlorophyll peak dates suggests that in many open ocean regions, blooms of coccolithophores and other phytoplankton can occur simultaneously, conflicting with the traditional view of species succession that is thought to take place in temperate regions such as the North Atlantic.

Photosynthetically available radiation (PAR), light in the 400-700 nm wavelength range, controls the growth of phytoplankton and ultimately regulates the composition and evolution of marine ecosystems. The goal is to produce a long-term, consistent time series of daily PAR over the global ocean from multiple satellite observations (e.g., Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), MODIS-Aqua, MODIS-Terra). To ensure consistency of the PAR data over time, estimates using data from one, two, or three sensors must be compared,

[11] To learn more about ocean color measurements see "NASA Sets the PACE for Advanced Studies of Earth's Changing Climate" in the July–August 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 4**, pp. 4-12]. In particular, there is a sidebar on page 5 describing "How Ocean Color Measurements Are Made."

[12] Coccolithophores are one-celled marine plants that surround themselves with a microscopic plating made of limestone. They live in large numbers throughout the upper layers of the ocean.

and statistical adjustment factors determined. Examples of monthly averaged global PAR for MODIS and VIIRS are shown in **Figure 3**. A 15-year time series showed consistency among instruments, but there was no obvious trend.

Sea Surface Temperature

The first presentation on sea surface temperature (SST) included a demonstration of the compatibility of MODIS-Terra and MODIS-Aqua SST retrievals with those of VIIRS. This is good news, as the production of a consistent data record between the two sensors is a necessary first step toward developing an accurate CDR for SST. Consistency over multiple missions is being achieved using comparable cloud-screening and atmospheric correction algorithms, and using the same approaches to estimate errors and uncertainties. SST accuracy requirements are very stringent, requiring traceability of calibration to International System of Units (SI) standards. A consistent data record is evolving, beginning with the AVHRR series (starting in 1982) and extending to the present with MODIS and VIIRS—although the AVHRR-through-MODIS datasets do not quite meet the standards. However, the MODIS and VIIRS data approximately meet the standards for SST. A deterministic inverse method, which uses total least squares (TLS) for SST retrievals from VIIRS, is being tested as an alternative to the traditional regression method. This ameliorates issues with instrument calibration and characterization but could result in regional and seasonal biases. A modified TLS (MTLS), generated with a reliable radiative transfer model, is highly applicable to VIIRS since it is a well-calibrated instrument.

Summary

Reports from the breakout groups and closing remarks from HQ personnel filled the last day's closing plenary session. In addition to highly pertinent science talks, many details were hammered out in the discipline breakout sessions—far too many to be summarized here. There were however some common threads to the discussion among all three discipline teams including:

- continuation and development of new validation assets;
- application of ancillary models (e.g., those from the Global Modeling and Assimilation Office (GMAO) and the Modern-Era Retrospective Analysis for Research and Applications (MERRA);
- Algorithm Theoretical Basis Document (ATBD) updates and submission;
- defining user community needs;
- establishing SIPS requirements for formats and data standards and release L1, L2, and L3 products;
- product documentation;
- Direct Broadcast and NRT data deliveries;
- MODIS (Collection 6) updates and application to VIIRS; and
- multisensor reprocessing and establishing long-term datasets.

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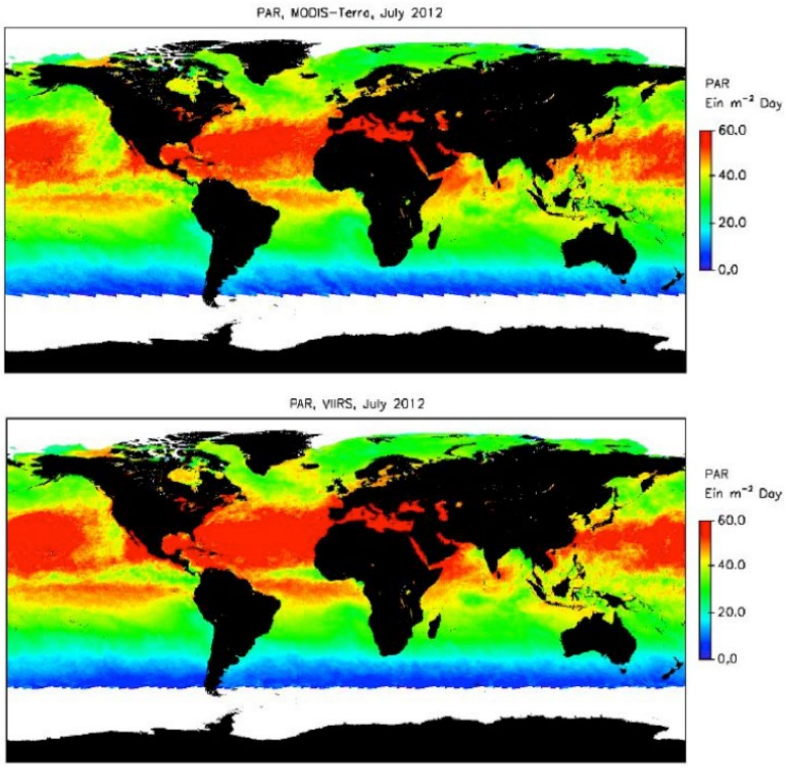

Figure 3. These maps show monthly PAR for July 2012 from MODIS-Aqua [*top*] and VIIRS [*bottom*]. PAR values from individual instruments were compared with those from combining three instruments (i.e., MODIS-Terra, MODIS-Aqua, and VIIRS). Monthly maps were then used to correct the estimates from individual instruments and produce a consistent multiyear time series of PAR imagery across sensors. Overall, the differences were of the order of a few percent after correction for clouds and the biases between instruments were removed. **Image credit:** NASA Ocean Biology Processing Group

Summary of the NASA LCLUC Spring 2015 Science Team Meeting

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Introduction

The NASA Land-Cover/Land-Use Change (LCLUC) Program held its annual spring Science Team Meeting (STM) on April 22-23, 2015, in College Park, MD[1]. The Science Team Meeting had two sessions: a half-day session on April 22 that focused on the ongoing Sentinel-2 preparatory studies, and a full-day session on April 23 that focused on the contribution of remote sensing to LCLUC modeling and scenarios with invited talks and project presentations from participants in the LCLUC Early Career Scientists program.

Session I: Sentinel-2 Data Preparatory Studies

The European Space Agency's (ESA) Sentinel-2 mission is a land-monitoring constellation of two satellites that will provide high-resolution optical imagery. Data from Sentinel-2 complement data from the current Landsat missions. The launch of the first satellite, Sentinel-2A, occurred June 23, 2015; Sentinel-2B will be launched in mid-2016.

Garik Gutman [NASA Headquarters (HQ)—*LCLUC Program Manager*] presented a brief overview of the Sentinel-2 (S2) preparatory components, Sentinel-2 Data Use Preparation (S2DUP) projects, and deliverables. He focused on how S2 data could be used synergistically with Landsat data to create higher-temporal-frequency coverage and higher-level LCLUC products. He also introduced the LCLUC Multi-Source Land Imaging (MuSLI) Science Team[2]. Gutman next discussed the utility of NASA Earth Exchange (NEX) in LCLUC projects and encouraged all LCLUC principal investigators (PIs) to register in the system and use it if they're processing large volumes of data. His presentation ended with a brief summary of the upcoming LCLUC-related meetings, which include the Mapping Urban Areas from Space, to be held at the ESA European Space Research Institute (ESRIN), November 4-5, 2015, and the First International MuSLI STM, to be held in conjunction with the twentieth anniversary LCLUC STM in the Washington, DC, area in April 2016.

Jeff Masek [NASA's Goddard Space Flight Center (GSFC)] followed with a status update on S2-Landsat integration. He highlighted how combining data from S2 with those from Landsat 7 and Landsat 8 (L8) offers 30-m (~98-ft) global coverage between 3 and 5 days, thereby providing the geographic coverage and temporal frequency required for many time-series-based applications in agriculture and forestry. The 13 spectral bands of S2 offer additional opportunities for vegetation analysis, correction for atmospheric perturbations, and land classification. The U.S. Geological Survey (USGS) Earth Resources Observation Systems (EROS) Data Center plans to provide a copy of the complete archive of S2 data, and will be the source of data for the MuSLI team. The path ahead looks promising; an agreement between the European Commission and

[1] The LCLUC STM was held in conjunction with the NASA Carbon Cycle and Ecosytems Focus Area meeting.

[2] The Multi-Source Land Imaging (MuSLI) Science Team is tasked with developing prototype algorithms for higher-level LCLUC products from mid-resolution optical sensors and radars. The MuSLI Science Team was formed under a Research Opportunities in Space and Earth Sciences (ROSES) 2014 grant and consists of seven principal investigators, their co-investigators, and international collaborators accounting for over 40 members.

2015 LCLUC spring STM participants. **Photo credit:** Sumalika Biswas

U.S. Department of State is in the process of being signed, which will allow the USGS S2 archive and distribution activities to proceed.

Radiometric Characterization and Calibration/Validation

This session included presentations from **Brian Markham** [GSFC]; **Larry Leigh** [South Dakota State University]; **Jeff Czapla-Myers** [University of Arizona]; and **Aaron Gerace** [Rochester Institute of Technology].

Markham presented an overview of the S2 and L8 characterization and cross-calibration. Compared to L8's Operational Land Imager (OLI), S2's Multispectral Instrument (MSI) has a wider swath and field-of-view, a shorter repeat cycle, comparable equatorial crossing time, and greater number of spectral bands. MSI also has a wider spectral response compared to OLI in the visible and near-infrared (VNIR) region. Orbital analysis of S2 and L8 revealed that the pattern of intersections of L8 and S2 coverage repeats every 80 days. For example, if on day 1, L8 images location A on the ground at 10:13 AM at a 15° angle and S2 images the same location at 10:30 AM at a 20° angle, the same pattern of observation will be observed at the same location (location A) 80 days later (on day 81). Comparison of instrument coverage showed that in some swaths there is near-simultaneous data acquisition from both platforms with the same view angles, while for others the same view angle may be obtained a day apart. For the continental U.S., S2 ground tracks move three orbital tracks to the east each day on the descending side. Comparative measurements of MSI solar diffuser witness samples and the ESA reference diffuser are being carried out at U.S. and ESA calibration facilities.

Leigh gave an update on the pseudo-invariant calibration sites based on calibration of S2 and L8. He highlighted the need for Spectral Band Adjustment Factor (SBAF) and Relative Spectral Response (RSR) comparisons for sensor calibration. RSR comparisons showed that between S2 and L8, responses of some bands are very similar while others are quite different. For example, the red bands of the two sensors appear to have less spectral overlap when compared to other bands in the visible region, while spectral responses are more closely matched for NIR, short wave infrared (SWIR), and cirrus bands. Furthermore, S2 has multiple NIR bands. SBAF compensation is necessary to evaluate true calibration differences. The SBAF was studied with reference to the spectral signature from targets used for calibrating the Hyperion imaging spectrometer onboard NASA's Earth Observing-1 (EO-1) satellite. The SBAF correction was found to be more important for the Enhanced Thematic Mapper plus (ETM+) compared to OLI. As a result, an improved absolute calibration model was developed that can be applied to MSI, postlaunch.

Czapla-Myers presented the plans for postlaunch radiometric calibration of MSI, proposed to be carried out at the Radiometric Calibration Test Site (RadCaTS) in central Nevada. RadCaTS is presently used to calibrate sensors, such as the ETM+, OLI, Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadioeter (MISR), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Visible Infrared Imaging Radiometer Suite (VIIRS), Hyperion, RapidEye, and WorldView-3.

Gerace discussed the development of the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model to facilitate cross-calibration between sensors and data normalization studies in support of S2–L8 calibration efforts. DIRSIG allows scene content, atmospheric opacity, and instrument performance to be specified, thus providing "synthetic" imagery from multiple sensing systems.

Harmonizing Sentinel-2 and Landsat Reflectance Products and Bidirectional Reflectance Distribution Function

This session included presentations from **Martin Claverie** [University of Maryland, College Park (UMD)]; **Eric Vermote** [UMD]; **Curtis Woodcock** [Boston University]; **Crystal Schaaf** [University of Massachusetts]; and **David Roy** [South Dakota State University].

Claverie provided an overview of the processing flow of the Harmonized Landsat Sentinel-2 (HLS) surface reflectance prototype products. The processing flow includes MSI and OLI atmospheric corrections, cloud masking algorithms, bidirectional reflectance distribution function (BRDF) and bandpass adjustment (for MSI only), and regridding of merged products. The planned HLS output product has a spatial resolution of 30 m (~98 ft) for OLI data, gridded in sinusoidal projection and a temporal resolution of approximately five days also in sinusoidal projection. MSI spectral bands that overlap with those from OLI will be adjusted, and the red-edge bands from MSI and the thermal band from OLI will be maintained in the output HLS product.

Vermote presented the MSI and OLI prototype atmospheric correction algorithm. The algorithm relies on recent improvements made to the MODIS Collection 6 surface reflectance product, and takes advantage of the additional coastal/aerosol blue band that was missing in previous Landsat sensors. Aerosol optical thickness (AOT) is retrieved at 30-m (~98-ft) spatial resolution using a spatially explicit map (derived from MODIS and MISR data analysis) of the ratio between the two blue bands and the red spectral bands. Some adjustments with respect to cloud and cloud shadow and retrieval over water remain to be implemented in the developing algorithm. The standard algorithm is

performing well for L8 surface reflectance (SR) and will be used to process synthetic MSI data.

Woodcock spoke on the utility of the Landsat and S2 bands in developing cloud-masking algorithms. He stated that improved cirrus cloud-detection algorithms will lead to better land-cover classification maps. He showed how cirrus clouds affect spectral reflectance in different regions of the spectrum. A comparison of cloud masks developed using each sensor showed that L8 and S2 performed far better than legacy Landsat sensors. This is because L8 with all three cloud-detection bands (optical, thermal, cirrus) performs better than S2, which has two cloud-detection bands (optical and cirrus). Legacy Landsat satellites (i.e., Landsats 4-7) with two cloud-detection bands (optical and thermal) perform the worst. Use of temporal information further improved the cloud masks.

Schaaf introduced the issue of BRDF effects that may affect the interuse of OLI and MSI SR products. The L8 albedo product algorithm and validation scheme were presented. OLI high-resolution surface albedo is based on OLI reflectances coupled with *a priori* BRDF information retrieved from MODIS products; the same strategy can be adopted for MSI. **Claverie** presented an evaluation study on high-spatial-resolution BRDF retrieval method using multi-angular SPOT4 (Take5)[3] data.

Roy discussed the gridding, projection, and compositing issues for the HLS product. Sinusoidal equal-area projection and inverse mapping, as used in the NASA-funded web-enabled Landsat Data (WELD) project, were found to be most suitable. The use of nearest-neighbor resampling was suggested to preserve the categorical and ordinal per-pixel quality assurance information after reprojection. The MODIS-tiling scheme with the nested WELD-tiling scheme seems most suitable for the merged product. The compositing algorithm will be similar to Global *Version 3.0* WELD processing flow, which incorporates use of BRDF adjustment factors.

Higher-Level Processing and Product Generation

This session included presentations from **Chris Justice** [UMD] and **Sangram Ganguly** [NASA's Ames Research Center].

Justice presented an overview of the potential higher-level products that could be generated from S2 and Landsat data. He pointed out that higher-level products for use in land-cover science are generated using MODIS imagery, but no such products have been generated from Landsat imagery. However, with increased acquisitions and available high-end computer processing, the concept of "global" Landsat data—i.e., with MODIS-like data products at 30 m (~98 ft)—is becoming a reality, and so these are indeed exciting times for the remote-sensing community. In the international context, the requirements for Essential Climate Variables (ECV) have been developed for products with coarse resolution ranging from 250 m to 1 km (~820 to 3280 ft). Land cover is perhaps the only ECV that is available at finer resolution between 10 and 30 m (~32 and 98 ft). Moderate-resolution imagery at higher temporal frequency is necessary to observe rapidly changing land conditions. Combining data from L8 and S2 satellites offers an opportunity for more-frequent observations. Other opportunities include merging data from L8 with data from similar spatial-resolution sensors like those onboard the China-Brazil Earth Resources Satellite (CBERS 4), Indian Resourcesat 2, and ESA's Sentinel-1A. Some of the higher-level products that may be developed from S2–L8 fusion include: a generic, uninterpreted change product; forest-cover change products; vegetation phenology products; leaf area index (LAI)/fractionally absorbed photosynthetically available radiation (FPAR); fire and burned area products; agricultural products (e.g., crop type, crop condition, crop residue); flooding extent; urban characterization; and built-area change. Justice recommended that product developers exercise caution when merging datasets from different sensors, since fusion approaches are still new.

Ganguly discussed the role of NEX in S2 processing flow and presented a comparison between simulated S2 and L8 with respect to red and NIR reflectance, normalized difference vegetation index (NDVI), and LAI.

Session I Summary and Conclusion

Jeff Masek led a summary discussion following the presentations. Some of the issues raised for discussion were:

- the need for more dialogue between the research communities at NASA and ESA;
- the confusion potential for multiple versions of S2 products; and
- agreement on the resolution of the merged products, compositing method, and the role of EROS *vs.* NEX in S2 data distribution.

Concerns were raised regarding the schedule for the S2 archiving at EROS, and data availability and the phased geographic extent of S2 acquisitions. The community members noted that there was no similar L8–S2 fusion product developed from the European side, which offers considerable potential for collaboration. The team recommended that a series of technical telecons and meetings be held once the S2 data acquisitions begin and as project funds are set up. **Garik Gutman** closed

[3] The SPOT4 (Take5) experiment uses the SPOT4 satellite as a simulator of the image time series that ESA's Sentinel-2 mission will provide. For more information, visit *spot-take5.org/client/#/home*.

the session with a remark that a *white paper* needs to be developed by August-September to facilitate more interaction and as a framework for ongoing research.

Session II. Contributions of Remote Sensing to LCLUC Modeling and Scenarios

Garik Gutman gave an update on the current status of the program and briefly introduced how NASA's LCLUC Program relates to the NASA Carbon Cycle and Ecosystems Focus Research Area meeting. He pointed out that among the international and regional LCLUC-supported networks, a new program focused on LCLUC research in South Asia, called the South Asian Research Initiative (SARI), and the NASA-ESA international MuSLI Science Team was formed since the last meeting. He also noted that previously supported networks [the Northern Eurasia Earth Science Partnership Initiative (NEESPI) and Monsoon Asia Integrated Regional Study (MAIRS)] are moving into the Future Earth[4] framework. He highlighted the significance of the recently published National Research Council's (NRC) report, *Advancing Land Change Modeling: Opportunities and Research Requirements,* which was partly supported by the NASA program and the USGS. He strongly encouraged both LCLUC and MuSLI PIs to promote their research by sharing their products with the broader LCLUC community through the newly formed Metadata section of the LCLUC website, as well on their individual project websites. In terms of outreach activities, the LCLUC Science Team has been interacting with the broader community through knowledge dissemination via online webinars, a Facebook page, and by publishing a new, quarterly newsletter.

With the backdrop of the much-discussed S2–L8 synergy and higher-level product generation in Session I, **Ioannis Manakos** [EARSeL[5] Special Interest Group on Land Use and Land Cover—*Chairman*] spoke on existing and potential areas of European collaborations with NASA's LCLUC Program, and highlighted current priorities on the European side. He emphasized how societal- and policy-driven studies funded in Europe are driving Earth-observation requirements and how, in return, Earth-observation data are increasingly being used to inform policy. He acknowledged that NASA's Earth-observation products are freely available and that historically the Landsat archive has played a significant role in supporting Earth-observation research in Europe. The first joint workshop of the EARSeL Special Interest Group on Land Use and Land Cover and NASA's LCLUC Program was held in Berlin in March 2014, and there is interest to continue these collaborative interactions.

Chris Justice followed with an outline of the objectives of the LCLUC meeting and agenda. The meeting was divided into four sessions: Contribution of Remote Sensing to LCLUC Modeling and Scenarios, Regional Program Development in Southern Asia (SARI), Early Career Scientists Reporting on their Research Results, and Discussion of Research Priorities for Remote Sensing in LCLUC Modeling and Scenarios.

Dan Brown [University of Michigan] highlighted the role of remote sensing in establishing LCLUC baseline and boundary conditions, expanding variables and measures, and enhancing land-change process models. He emphasized integrating remote sensing data with socio-economic data to transition to a process-based model, reflecting on the role of humans in land-use models as compared to biophysical modeling.

Richard Moss [Pacific Northwest National Laboratory, Joint Global Change Research Institute] summarized the U.S. Global Change Research Project (USGCRP) workshop on LCLUC scenarios. The Scenarios and Interpretive Science Coordinating Group of USGCRP held a workshop from June 25-27, 2014, that focused on subnational LCLUC scenarios, which identified gaps and challenges relating to inconsistencies in data; missing data; scaling issues in modeling and scenario development; understanding relationships across disciplines; and model integration issues.

Introduction to LCLUC Modeling and Scenarios in the U.S.

This session included presentations from **Scott Goetz** [Woods Hole Research Center]; **Yuyu Zhou** [Pacific Northwest National Laboratory, Joint Global Institute]; and **Kelly Cobourn** [Virginia Tech].

Goetz discussed the modeling strategies for adaptation to coupled climate and land-use change in the U.S. Of the four Representative Concentration Pathways (RCP) investigated, RCP 8.5 showed substantial changes in gross primary productivity (GPP) compared to RCP 4.5. Run-off was reported to be subtle for the U.S. on average, but subject to dramatic regional and seasonal variations.

Zhou described urban-expansion modeling scenarios. Using a cluster-based method to map urban areas using night light data, he developed a Global Urban Extent map. The map can be used to investigate future urban energy use under various scenarios of urban growth and climate change.

Cobourn showed how water rights, water source, and climate variability impact water availability, which in turn influences land allocation decisions. In the Snake River Basin in eastern Oregon and Idaho, for example, low or variable water availability was associated with

[4] Future Earth is an international hub to coordinate new, interdisciplinary approaches to research on three themes: dynamic planet, global sustainable development, and transformations towards sustainability. For more information, visit *www.futureearth.org*.

[5] EARSel stands for European Association of Remote Sensing Laboratories.

sowing of drought-resilient crops (e.g., sugar beets) and with letting fields lie fallow. Irrigators who own senior surface-water rights allocated more land to water-intensive crops like alfalfa, while the junior surface-irrigators preferred more drought-resilient crops like sugar beets. The same effect was less pronounced among groundwater irrigators.

The LCLUC South Asia Regional Program

Krishna Vadrevu [UMD] introduced the newly established South Asia Research Initiative (SARI). The objective of SARI is to advance LCLUC science in the South Asian region and facilitate the development of new partnerships between the national and international space agencies, universities, and nongovernmental organizations; enhance data sharing mechanisms and development of regional LCLUC products; and build capacity. A new SARI website is currently being constructed. A background document containing all relevant information has been developed and will be available from the website. The SARI is focused on the following broad areas: agricultural LCLUC, land-atmosphere interactions, urban LCLUC, and forests and LCLUC. In this connection, the current NASA LCLUC ROSES-2015 call has a focus on South Asia, and the next LCLUC international meeting is scheduled to be held in Myanmar in January 2016.

LCLUC Impacts in Northern Eurasia

This session included presentations from **Kirsten de Beurs** [University of Oklahoma] and **Jessica McCarty** [Michigan Technological University].

de Beurs discussed the significant role played by rural population density and ethnicity in Russia's agricultural developments and global food security. Using MODIS surface phenology and Landsat land-cover data she investigated regional variation in agricultural patterns and related it to regional demographics. de Beurs concluded that regions in southern Russia show more variability in agricultural patterns than the regions in northern Russia due to adaptation measures by communities in the face of drought.

McCarty presented the relationship between fire regimes and land abandonment in European Russia, stating that she found more fires over stable nonforested areas due to the presence of hay and pastureland, and investigated the socioeconomic determinants of human-induced fires.

LCLUC Impacts in Asia and Pacific

This session included presentations from **Stephen Leisz** [Colorado State University] and **Jason Julian** [Texas State University].

Leisz showed how improved transportation routes along the Southeast Asian East-West Economic Corridor impact LCLUC in the region. He found that increased connectivity between countries led to changes in farming systems, rural urbanization, increased cross-border trade and increased tourism, all of which resulted in growth of residential and industrial built-up areas.

Julian focused on the impacts of land management on water quality across multiple scales in New Zealand. He showed the first-ever comparison of 8-day land-cover change at 30-m (~98-ft) spatial resolution with long-term water quality datasets. Comparison of the disturbance index from the above dataset, combined with water clarity data, showed that increased disturbance in the watershed leads to a decrease in water clarity.

LCLUC Impacts in Africa and Latin America

This session included presentations from **Michael Coe** [Woods Hole Research Institute]; **Kelly Jones** [Colorado State University]; **Greg Husak** [University of California, Santa Barbara]; **Gillian Galford** [University of Vermont]; and **Tatiana Loboda** [UMD].

Coe discussed past transitions in LCLUC in the Cerrado—a vast tropical savanna ecoregion of Brazil—and modeled the future with respect to human and biophysical drivers of change and its impacts on the ecosystem. His research showed that policies favoring agricultural intensification over extensification may be more effective in meeting the dual objectives of reducing deforestation and meeting the global demands for agricultural products.

Jones showed how land cover and land use has changed between 1986 and 2010 in Montecristo Trifinio Trinational Park, a transboundary protected area in Central America. Currently, Jones and his research team are investigating the drivers of change and the effectiveness of the transboundary protected areas in conserving the forest cover.

Husak described the impacts of variable food availability on nutritional status in the context of climate change. For example, in West Africa, a decrease in crop production by 25% resulted in an increase in stunting growth in 34-38% children, while an increase in crop production resulted in increased births.

Galford presented the environmental and socioeconomic outcomes of the New African Green Revolution in Malawi. She showed how a fertilizer subsidy in Malawi led to improved yields and helped the nation progress towards their millennial development goals.

Loboda showed how global governance affects land-use decisions. In Subsaharan Africa, stronger capacity to aspire for development and poverty reduction was related to reductions in forest clearing. However, high-level aspirations for development and poverty reduction, when coupled with limited alternatives, were linked to potential species extinction.

Session II Summary Discussion

After the presentations in this session, **Dan Brown** moderated a concluding discussion. Prioritizing management inputs such as fertilizer applications and irrigation in remote-sensing products was suggested. The need to divide forestland into well-defined categories for use in integrated assessments was also raised. The community also acknowledged the lack of knowledge on the role of climate variability, shocks, short-term drivers, and variability in long-term trajectories, as well as extreme events in LCLUC processes. The absence of human factors in model parameters was also recognized as a gap that needs to be filled. Earth System Integrated Assessments lack the land-cover data needed to include human influence on scenarios. Remotely sensed disturbance datasets along with socioeconomic data could help to fill this gap. The issue of scaling remotely-sensed datasets to fit model temporal and spatial resolution was also raised. Downscaling and the need to constrain models were identified as a priority area. Currently there is no established methodology to scale 30-m (~98-ft) pixels for large-scale models. Both the remote-sensing and modeling communities need to work together to develop robust methods to address this topic.

Validation of models was recognized as another problem area, with very limited attention currently given to model validation. Categorical differences in land cover complicates the task of validation. Information on land-management boundaries is either lacking or outdated. In the absence of adequate time-series of land-cover data needed to initialize models, models struggle with initial depiction of land cover. Moreover, the uncertainty in some land-cover products, such as LAI or MODIS GPP, further complicate the problem. Land-surface models are known to perform poorly in Northern Eurasia with respect to GPP and ecosystems. The lack of historical time-series, e.g., 400-500-year-old data, not available through remote sensing, was identified as another gap. The creation of consistent multi-decadal LCLUC products from remote sensing is a high priority that needs to be addressed through future continuity missions and international cooperation.

Concluding Discussion

Chris Justice led a wrap-up discussion, addressing the gaps in remote-sensing products to provide an input to modeling. Filling the gaps would require the combined effort of both the remote sensing and the land-cover/land-use modeling communities, working together to develop community-level models. This calls for larger group-level funding, as previously seen in the Interdisciplinary Science (IDS) investigators, funded as part of NASA's Earth Observing System. Apart from NASA, other organizations—like the U.S. Department of Agriculture, the U.S. Forest Service, the U.S. Department of Energy, and other organizations that benefit from land-use modeling research—might be brought together, for example, under the rubric of the U.S. Global Change Research Program (USGCRP) to expand support for such interdisciplinary studies. Presently, a lot of organizations use land-use models and end-user products in their research, but few are willing to invest in a much needed "community model" development effort. Integrating social science with remote sensing has always been a value-added dimension in NASA's LCLUC Program. Availability of high-resolution data free of charge from the National Geospatial-Intelligence Agency (NGA) has added stronger impetus to study social processes at higher resolutions than ever. Justice encouraged industry-university partnerships to promote LCLUC research.

Dan Brown moderated the Summary Discussion of the role of remote sensing in LCLUC, modeling and developing future scenarios. **Photo credit:** Sumalika Biswas

Garik Gutman closed the meeting, emphasizing the need to balance the available program funds between specific fields and researchers at different stages of their careers. He noted that NASA's Early Career Scientists initiative has been a huge success, bringing new talents to the forefront. He noted the need to balance support for remote-sensing research, such as the new MuSLI effort, while ensuring that social science remains an integral part of the program. Gutman encouraged the meeting participants to:

- promote LCLUC Program research through outreach activities such as those populating the newly developed Metadata page on the LCLUC webpage;
- publish articles in the new LCLUC quarterly newsletter;
- participate in online webinars;
- continue the semi-annual meeting structure; and
- check the proposal calls on a regular basis.

To close, Gutman encouraged the community members to promote their research and foster collaborations to strengthen the LCLUC research community. ■

Kudos

Jack Kaye [NASA Headquarters—*Associate Director of Research for the Earth Science Division*] received the *Asia Oceania Geosciences Society (AOGS) Honorary Member* award during the AOGS 12th Annual Meeting held in Singapore in August 2015.

AOGS created this prestigious award to honor the persons whose international standing in geosciences or whose services to the Society are recognized by the Society and elected by the General Meeting.

The Award Committee evaluates and ranks the nominated candidates and then submits its recommendations and the ranked list to the Council, at least three months prior to the next AOGS Annual General Meeting, for consideration and approval. The criteria for ranking, each of equal weight, are any two of the following three criteria:

- The excellence, outstanding nature, breadth, persistence, and international recognition of a candidate's research contributions to the geosciences;
- The excellence and duration of a candidate's record of international leadership and unselfish cooperation in the geosciences, particularly in Asia and Oceania;
- The excellence and duration of a candidate's contributions to AOGS, especially relating to the development of the geosciences within Asia and Oceania and to international cooperation within and outside these regions.

Please join us in congratulating Jack on this award!

meeting summaries

ESIP Federation Summer Meeting Addresses Data-Driven Community Resilience

Rebecca Fowler, Foundation for Earth Science, rebeccafowler@esipfed.org

Introduction

The Federation of Earth Science Information Partners (ESIP Federation) is a broad-based, distributed community of Earth science data and information technology practitioners that spans U.S. government (e.g., NASA, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, U.S. Geological Survey (USGS), U.S. National Science Foundation), academic, and private sector organizations (both commercial and nonprofit). Initiated by NASA in 1997, member organizations of the ESIP Federation facilitate data distribution and provide products and services to decision makers and researchers in public and private settings. Community members leverage collaboration and coordinate interoperability efforts across institutional, geographic, and disciplinary boundaries. Partners use these independent forums for knowledge exchange and collaboration as an *intellectual commons*—where practitioners work together to solve common challenges. Partnership in the ESIP Federation is voluntary, and open to organizations that work at the intersection of Earth science data and supporting technologies. ESIP Federation members represent a wide range of organizations with Earth Science data interest. Each member organization selects a representative from their staff to belong to the ESIP Federation Assembly, or governing body. The Foundation for Earth Science provides management services to the ESIP Federation.

The ESIP Federation held its 2015 Summer Meeting[1] at the Asilomar Conference Center in Pacific Grove, CA, July 14-17. Nearly 300 leading scientists and data and information technology practitioners were in attendance. The theme of the meeting was the *ESIP Federation and Community Resilience: Coming Together*. Resilience is the capacity of individuals, communities, and systems to survive, adapt, and grow in the face of stress and adversity. Building resilience makes society better prepared to endure catastrophic events and able to respond to and emerge stronger from such challenges.

During the 4-day meeting, 8 plenary talks, 62 breakout sessions, and more than 50 poster contributions covered topics including data stewardship, evolving data products, interoperability, and citation and usability issues. In addition, a one-day professional development workshop for educators was held July 16, 2015.

Full meeting proceedings are available at *commons.esipfed.org/2015SummerMeeting*. For a list of highlights from 2015 see *2015 ESIP Federation Highlights* on page 30.

Federation Growth

Membership in the ESIP Federation continues to grow: There are now 173 member organizations. Members are divided into three categories: data providers (Type I), researchers (Type II), and application developers (Type III). In the first six months of 2015, 16 new ESIP Federation member organizations were added; the 7 member organizations of the Spring/Summer 2015 ESIP Federation Class were welcomed at the Summer Meeting—see **Table**.

As the ESIP Federation expands, it is important that the community remains inclusive and accessible to new and long-time members. With this in mind, during the first half of 2015 the Federation developed and announced an app called *ESIP Connects*[2] to enhance

[1] To read a summary from the 2014 Winter Meeting, see *ESIP Federation's 2014 Winter Meeting: Celebrating 15 Years of Activity* in the March-April 2014 issue of *The Earth Observer* [**Volume 26, Issue 2**, pp. 34-35].

[2] The app is freely available for iPhone and Android at *visitors.genie-connect.com/esipsummermeeting/#!visitordashboard_-42*.

Table. New member organizations welcomed at the ESIP Federation Summer Meeting.

Member Organizations	Member Category
Center for Ocean-Atmospheric Prediction Studies, Florida State University (COAPS)	Type II
Center for Research in Water Resources (CRWR)	Type II
Liquid Robotics, Inc.	Type I
Monterey Bay Aquarium Research Institute (MBARI)	Type II
U.S. Global Change Research Program, GCIS Team (USGCRP GCIS)	Type II
University of California Natural Reserve System	Type II
University of New Mexico Library	Type II

the ESIP Federation meeting experience by allowing attendees to more easily find meeting information and connect with each other. The app underwent a successful pilot roll-out at the 2015 ESIP Federation Winter and Summer Meetings; it will continue to be refined and used at future meetings.

Breakout Sessions

A variety of breakout sessions spanned the four-day meeting. These covered all levels of technical expertise and allowed attendees to showcase their research and discuss how technology enables communities to "bounce forward" in the face of shock and stress due to the effects of natural and manmade phenomena. Sessions were organized around four themes: data stewardship, information technology, developing resilient communities, and societal benefit. The scientific and technical topics ranged from the need for Earth science data analytics to help facilitate community resilience, to how to effectively deliver remote sensing products to meet disaster and risk management user needs.

A fifth track devoted to workshops provided an opportunity for attendees to learn new skills. Offerings included a daylong event on how to use *Drupal*[3] for online science collaboration and content management, and a one-day workshop led by the HDF Group on new Hierarchical Data Format (HDF) tools and technologies.

Plenary Session

There was a half-day plenary session on July 15 that focused on community resilience, with an introduction from **Peter Fox** [Rensselaer Polytechnic Institute—*ESIP Federation President*]. Plenary speakers addressed the data-driven technical, social, and scientific aspects of community resilience as it relates to open-source software projects, data archives' long-term planning, organizational change, and the use of Earth science data and technology for community resilience. The following is a summary of the speakers and the topics they addressed:

Bruce Goldstein [University of Colorado Boulder] framed collaborative resilience as it applies to place-based and virtual networks.

Kathleen Weathers [Cary Institute of Ecosystem Studies; Global Lake Ecological Observatory Network (GLEON)] shared lessons learned from the application of resilience concepts to the GLEON virtual community.

Lauren Casey [Sonoma County Regional Climate Protection Authority] discussed the efforts of the Climate Ready Sonoma County project in creating a climate-resilient community.

Dave Blodgett [USGS] outlined the dynamics of community resilience and how to manage varied community expectations.

Lawrie Jordan [Esri] described how geographic information systems (GIS) can facilitate the use of Earth science data by local communities to enable resilience. Jordan gave an overview of how GIS-based maps and visualizations assist with science storytelling, comparing NASA public outreach efforts of the 1970s with the agency's much more sophisticated—and successful—digital initiatives of today.

Sangram Ganguly [NASA's Ames Research Center] spoke about the big data challenges that arise from the implementation of satellite platforms, and the NASA Earth Exchange (NEX) and OpenNEX initiatives[4]. He gave an overview of OpenNEX features, and described how the platform enables both commercial and public sectors to better utilize NASA data.

David Lubar [Aerospace Corporation] explained the challenges faced in sharing the portions of the electromagnetic (radio) spectrum used by weather satellites with terrestrial networks that wish to use the same range of frequencies.

Chris Waigl [University of Alaska Fairbanks], the recipient of the 2015 Robert G. Raskin Scholarship, spoke about data usability in relation to remote sensing of Alaskan wildfires. Waigl implements a processing workflow that combines near-real-time satellite imagery with GIS data, and performs processing with algorithms that were specially adapted to interior Alaska's boreal zone.

Following the plenary session, in-depth conversations that began during a roundtable lunchtime discussion carried over into a special half-day Community Resilience Workshop. This particular discussion resulted in the development of a framework that will enable the identification of gaps in available data, knowledge, and necessary technology and the development of a set of data-related protocols, best practices, and standards to support community resilience.

Education Workshop

An ESIP Federation-sponsored education workshop was held on July 16; **Margaret Mooney** [Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison] led the workshop on integrating Earth science data into the ninth-through-fourteenth-grade science curriculum. Seventeen

[3] *Drupal* is an open source content management platform powering millions of websites and applications. It's built, used, and supported by an active and diverse worldwide community.

[4] NASA Earth Exchange (NEX) and OpenNEX are platforms for scientific collaboration, knowledge sharing and research for the Earth science worldwide community.

California high school science teachers and community-college faculty attended the workshop. Educators were introduced to a suite of online data and tools, including:

- The analysis and visualization of data from the NASA Socioeconomic Data and Applications Center (SEDAC), led by **Robert Downs** [Center for International Earth Science Information Network (CIESIN)];
- NASA's Lunar Mapping and Modeling Project (LMMP), taught by **Emily Law** [NASA/Jet Propulsion Laboratory (JPL)]; and
- MY NASA DATA, led by **Preston Lewis** [Science Systems and Applications, Inc.].

FUNding Friday

On July 17 the ESIP Federation held FUNding Friday, its annual mini-grant funding competition. The competition showcases how the ESIP Federation leverages current technologies and member skills to add new services with a modest amount of effort and funding. It also encourages collaborations across ESIP Federation member organizations that demonstrate the value of ESIP Federation participation. There were six FUNding Friday winners at the 2015 Summer Meeting: Four students received $3000 each for their respective projects, and three ESIP Federation members received $5000 prizes. In addition, $8000 in seed funding was provided to the new ESIP Drone Cluster to support the design and development of a drone.

Conclusion

The ESIP Federation continues to seed innovation, develop best practices and advance technologies across broad-based, distributed communities of science, data and information technology practitioners. In this light, ESIP Federation President **Peter Fox** said that, "ESIP Federation meetings are highly productive, successful events that spark new collaborations and ideas, and serve to advance the mission of the organization while meeting the professional development needs of our members."

The ESIP Federation hopes to see many new participants and returning attendees at the ESIP Federation Winter Meeting, January 6-8, 2016. The event will be held at the Wardman Park Marriott in Washington, DC.

2015 ESIP Federation Highlights

- In spring 2015, the Foundation for Earth Science welcomed four new staff members. **Annie Burgess** is the new ESIP Federation Community Director, **Rebecca Fowler** filled the position of Communications and Outreach Director, and **Dan Keyes** and **Annie Keyes** share one full-time operations and logistics position.
- A new ESIP *cluster*[1] that focuses on the use of drones (or unmanned aerial vehicles) in the Earth sciences was formed in early 2015 in response to the high level of interest shown in drone development and use at the ESIP Winter Meeting. Any ESIP organizational or individual member interested in discussing drone use is welcome to join the cluster; visit *wiki.esipfed.org/index.php/Drone_Cluster* to learn more about the *Drone Cluster*.
- ESIP President **Peter Fox** was named a 2015 fellow of the American Geophysical Union (AGU). Fox is a long-time ESIP member and was elected president of ESIP in 2014. He has made significant contributions to the fields of distributed semantic data frameworks, ocean and environmental informatics, computational sciences and cognitive computing, digital humanities, exploratory large-scale visualization, and solar and solar-terrestrial physics.
- The popular science communication event *Ignite@AGU* will return to the 2015 AGU Fall Meeting in San Francisco, CA. Sponsored by NASA's Applied Sciences Program and held in partnership with the ESIP Federation and AGU's Earth and Space Science Informatics Section, the event enables scientists to showcase their interests through fast-moving, creative presentations. Ignite@AGU is scheduled for Wednesday, December 16, 2015, from 6:00-8:30 PM at Infusion Lounge. Contact *rebeccafowler@esipfed.org* if you're interested in presenting.

[1] A Cluster is an informal group within ESIP, consisting of members with a shared interest. Clusters receive infrastructure support from ESIP to facilitate discussion and collaboration around that interest.

2015 CLARREO Science Definition Team Meeting Summary

Amber Richards, Science Systems and Applications, Inc., amber.l.richards@nasa.gov
Rosemary Baize, NASA's Langley Research Center, rosemary.r.baize@nasa.gov
Bruce Wielicki, NASA's Langley Research Center, bruce.a.wielicki@nasa.gov

Introduction

The seventh meeting of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Science Definition Team (SDT) was held at the Lawrence Berkeley National Laboratory (LBNL) in Berkeley, CA, April 28-30, 2015. Over 25 investigators participated in the meeting, which included 27 presentations. Attendees were from NASA Headquarters (HQ), NASA's Langley Research Center (LaRC), NASA's Goddard Space Flight Center (GSFC), NASA/Jet Propulsion Laboratory (JPL), University of Wisconsin, Harvard University, University of Michigan, University of California-Berkeley, University of Miami, University of Colorado's Laboratory for Atmospheric and Space Physics, McGill University, and Imperial College in London.

The meeting was an opportunity to provide an update on the status of a possible pathfinder mission, included in the President's FY16 budget request, that would be launched to the International Space Station as a proof-of-concept for the full CLARREO mission; report on science study progress and future studies for the Infrared (IR), Reflected Solar (RS), and Radio Occultation (RO) instruments; and plan for a white paper in response to the next National Research Council (NRC) Decadal Survey.

A few of the highlights from the presentations given at the meeting are summarized below. All of the presentations can be viewed online at *clarreo.larc.nasa.gov/events-STM2015-04.html*.

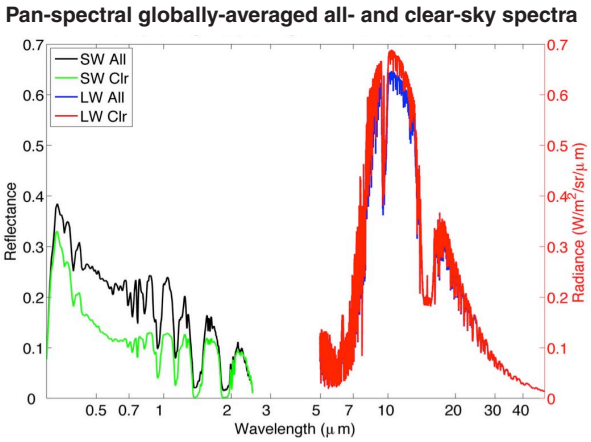


Figure 1. Globally averaged shortwave-all-sky (SW All); shortwave-clear-sky (SW Clr); longwave-all-sky (LW All); and longwave-clear-sky (LW Clr) spectra from the CLARREO OSSE. **Image credit:** Lawrence Berkeley National Laboratory

Attendees at the CLARREO SDT Meeting in Berkeley, CA. **Photo credit**: Lawrence Berkeley National Laboratory

Meeting Highlights

Far-Infrared Surface Emissivity and Climate

Daniel Feldman [LBNL] highlighted important progress that has been made on observing system simulation experiments (OSSE) in the short- and long-wave infrared spectral regions for climate model evaluation—see **Figure 1**. This effort represents the culmination of approximately three years of work and presents a path forward to understanding the characteristics of hyperspectral observational records needed to construct models and perform inline instrument simulations. Such simulation will enable a diverse set of comparisons between model results from coupled model intercomparisons and existing and proposed satellite instrument measurement systems, e.g., CLARREO.

Ultra-Fast Radiative Transfer Model for Hyperspectral Instruments like CLARREO

Analyzing data with thousands of spectral channels is a time-consuming process. The bottleneck is the radiative transfer (RT) model. **Xu Liu** [LaRC] discussed how a principal component-based radiative transfer model (PCRTM) has been developed to reduce the number of RT calculations needed in the frequency domain. The PCRTM was chosen because it is approximately 1000 times faster than channel-based RT models. The team showed that they further sped up the PCRTM using an effective multiple scattering stream method that allows for a five-millisecond-per-spectrum

meeting summaries

computational time for instruments like CLARREO[1]. This method has shown to be between three and five orders of magnitude faster than discrete ordinants radiative transfer (DISORT) multiple scattering calculations, with accuracy better than 0.03 K.

Lunar Calibration Observation Requirements for the CLARREO RS Instrument

In April 2015, **Tom Stone** [U.S. Geological Survey (USGS)] joined the CLARREO SDT, bringing with him his expertise on using the USGS Robotic Lunar Observatory (ROLO)—*www.moon-cal.org*. This lunar calibration model was added in order to advance development of observational requirements for acquisition of lunar measurements by the RS instrument. Earth's moon is an ultrastable reflectance target and therefore—through application of a lunar model—can be used as a calibration transfer standard.

Stone provided more detail on the current lunar calibration efforts, the objective of which is to derive operational requirements for the RS measurements of the moon. Completed tasks include initial orbit and lunar observation simulations for a 90° polar orbit. In-progress work includes lunar observation simulations for the orbit of the International Space Station (ISS), including field-of-regard constraints for the Japanese Experiment Module–Exposed Facility (JEM-EF) deployment, adjacent payloads, and ram direction, as well as a feasibility study for acquiring a new lunar characterization dataset for irradiance and reflectance modeling. The long-term vision for CLARREO lunar calibration is to use the moon as a transfer target for intercalibration with the CLARREO RS instrument.

Deriving Polarization Properties of Desert-Reflected Solar Spectra with PARASOL Data

Reflected solar radiation from the desert is strongly polarized by sand particles. To date there is no reliable desert surface reflection model that calculates the desert reflection matrix. For this study, **Wenbo Sun** [LaRC] used data from the polarimeter instrument onboard PARASOL[2], to retrieve the physical properties of the desert environment. The data (taken at three polarized channels at 490, 670, and 865 nm) were used in the Adding-Doubling Radiative Transfer Model (ADRTM) to calculate polarization of desert-reflected light for the entire solar spectrum—see **Figure 2**. Results from this study showed that using the physical properties of the desert's surface, the polarization state of radiation from the desert at any solar wavelength, incident angle, and viewing geometry can be obtained using the ADRTM. With this approach, 80% of the Earth's surface polarization spectra (covering ocean and desert) can now be modeled. Future studies will model the polarization state from snow/ice and vegetation surfaces.

[1] These instruments include the Infrared Atmospheric Sounding Interferometer (IASI) onboard the European Space Agency's MetOp series of satellites, Cross-track Infrared Sounder (CrIS) onboard the Suomi National Polar-orbiting Partnership, Atmospheric Infrared Sounder (AIRS) onboard Aqua, National Polar-orbiting Operational Environmental Satellite System Airborne Sounder Testbed Interferomenter (NAST-I), and the Scanning High Resolution Interferometer Sounder (S-HIS).

[2] PARASOL stands for the Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar.

Comparing model results with satellite data at a wavelength of 490 nm and a Solar Zenith Angle (SZA) of 28.77°

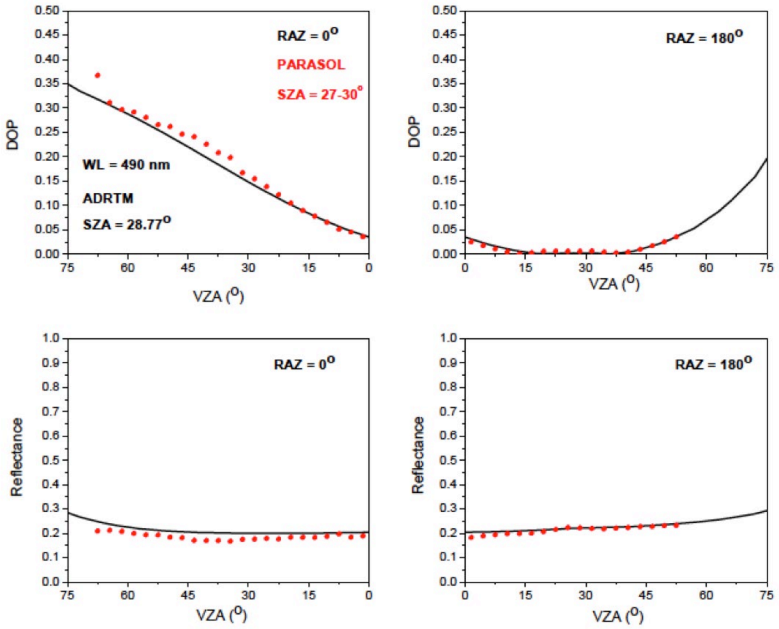


Figure 2: The graphs show that, based on a physical model for desert surface, the polarization state of the desert-reflected solar radiation at any wavelength in the whole solar spectra can be calculated with the ADRTM. This will provide accurate polarization distribution models (PDM) of desert surfaces for correction of satellite data that have errors due to the polarization of reflected light and the polarization dependence of the instrument. **Image credit:** NASA's Langley Research Center

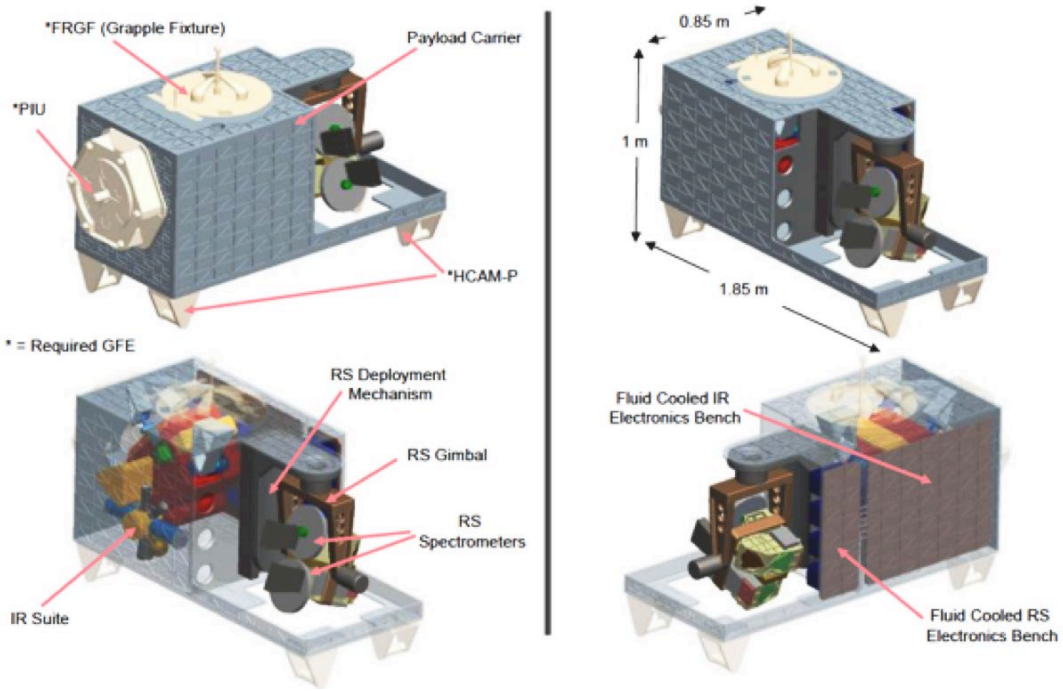


Figure 3: The CLARREO-ISS payload concept is compatible with the JEM-EF. **Image credit**: LaRC

CLARREO Mission Updates

Bruce Wielicki [LaRC—*CLARREO Mission Scientist*] provided the latest information regarding the CLARREO alternative mission studies. In 2013 the team demonstrated that both the RS and IR instruments could be readily accommodated on the JEM–EF on the ISS. In 2014 the team responded to a request for ISS technology demonstration ideas from the Earth Science Division at NASA HQ and provided subsequent data on the science that would be performed. In February 2015 the President's Budget Request included a line item for the CLARREO Pathfinder Mission—a technology demonstration mission—to start in FY2016 with a launch of the RS and IR instruments to the ISS in FY2019 followed by two years of operation. The instruments are expected to operate from ISS ExPRESS Logistics Carrier (ELC) 1, with a mounting site as yet to be determined.

Ultimately, the objective of these studies is to reduce risk and provide confidence that the full CLARREO mission can achieve the science goals. Wielicki emphasized, however, that the CLARREO Pathfinder mission (should it receive funding) is not the CLARREO mission; rather, it is a necessary step towards a successful CLARREO mission.

Based on NASA HQ guidance, the mission would be categorized as a Class D/Category 3 mission as specified in *NPR 7120.5E*[3], with the requirements tailored as necessary to meet the limited budget available. The concept would include both IR and RS instruments and the ISS would provide the location and accommodation guidance—see **Figure 3** for a rendering of how the instruments could be mounted on the JEM–EF. Future mission development steps include finalizing approval of recommended Class D implementation approaches, completing an accommodations feasibility study for both instruments on the ELC, conducting an acquisition strategy meeting, and formalizing partners and a project team.

[3] To read the guidance, visit *www.nasa.gov/pdf/423715main_NPR_7120-5_HB_FINAL-02-25-10.pdf.*

Next Steps and Moving Forward

The meeting concluded with a discussion of the next steps that the CLARREO SDT needs to take, including the following:

- Make progress on the alternative mission studies by proceeding with the next steps identified during the meeting.
- Continue to advance the science by publishing key journal papers on CLARREO orbit sampling, IR and RS intercalibration sampling, Instrument Incubator Program (IIP) and Calibration Demonstration System (CDS) calibration methods and accuracy levels, and the economic value of higher-accuracy climate observation missions (such as CLARREO).
- Host a discussion with members of the observation and climate modeling communities to discuss strategic planning efforts for observations needed to improve climate models.

The next CLARREO SDT meeting is scheduled to take place in Hampton, VA, December 1-3, 2015. ■

blog log

Blog Log

Heather Hanson, NASA's Goddard Space Flight Center/Global Science and Technology, Inc., heather.h.hanson@nasa.gov

This periodic installment features entries in blogs related to NASA's Earth-science research and fieldwork, and provides links to access the respective full blogs and to view color photographs online. In this issue we highlight three recent entries in NASA's *Notes from the Field* blog.

If you know of any blogs that should be shared in the *Blog Log*—perhaps one of your own—please email **Heather Hanson** at *heather.h.hanson@nasa.gov*.

[Blog introductions are modified from text in the featured blogs, which are also the sources for the images provided here.]

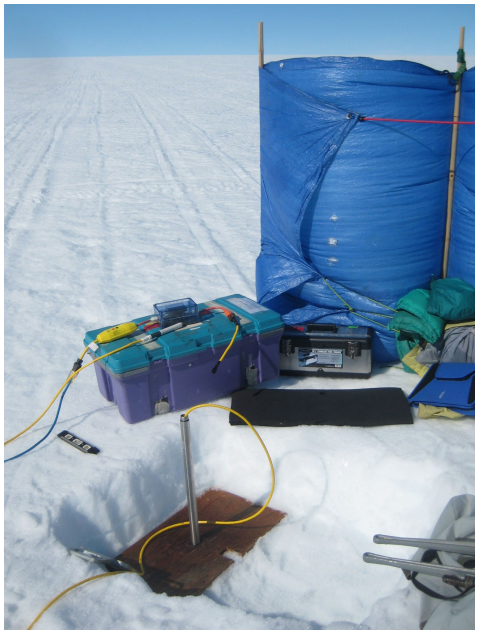
Greenland Aquifer Expedition

The Greenland Aquifer Team would like to welcome you back to the third installment of their blog. In 2015 the team is studying the water hidden below the surface of the Greenland Ice Sheet.

This season should be an exciting one. The National Science Foundation (NSF) and NASA have funded the team to do a lot more work this season to better understand how much water is being stored in the Greenland Ice Sheet and what that ultimately means for everyone on Earth. Over the next few decades the melt from Greenland will raise global sea levels. The only remaining questions are how much and how fast? The Greenland Aquifer Team will play a small roll in answering these science questions by drilling, pounding, radiating, and penetrating the aquifer in southeast Greenland.

Everyone on the team will contribute to the blog. Follow along at *earthobservatory.nasa.gov/blogs/fromthefield/category/greenland-aquifer-expedition*.

View from the June 22, 2015 flight into Kulusuk, Greenland, with broken-up sea ice (flat round ice) and icebergs that have calved from the nearby glaciers (taller, more jagged ice). **Image credit:** NASA

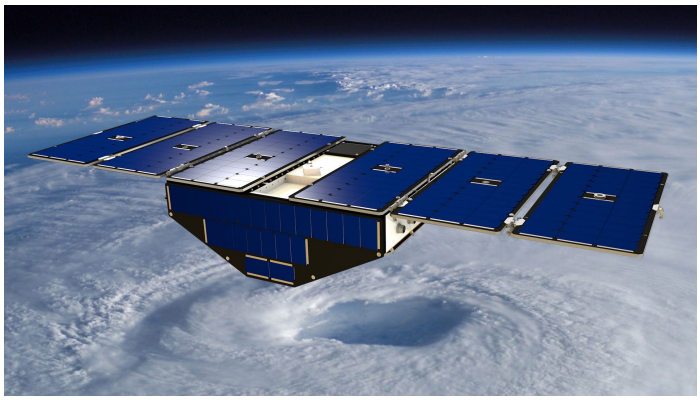


Favorable weather conditions allowed the team to drill into the Greenland aquifer at two sites for their hydrology work. This photo shows one of two temporary wells that were drilled in Kulusuk, Greenland. **Image credit:** NASA

Cyclone Global Navigation Satellite System

In October 2016 NASA will launch a constellation of microsatellites called the Cyclone Global Navigation Satellite System (CYGNSS[1]). The primary goal of the mission is to better understand how and why winds in hurricanes intensify, which is interesting from both scientific and practical points of view. CYGNSS is a unique satellite mission for many reasons.

Each of the eight CYGNSS satellites carries a global positioning system (GPS) receiver that measures the strength of the signal that is being forward-scattered off the ocean's surface. This signal is related to the roughness of the ocean and the strength of the wind. In this case, if the signal is strong, then the ocean is calm and there is not much wind, and if the signal is weak, there is a lot of wave activity, and the wind speed is strong. Using GPS receivers—and therefore not requiring transmitters—the satellites can be small and quite light, about the size of a microwave oven, and weighing only about 60 lb (27 kg). This allows NASA to launch eight satellites as opposed to one. In addition, the price for those eight satellites is quite a bit smaller than the price for a single, larger satellite. On the other hand, smaller satellites have certain shortcomings to larger ones. Having both types of satellites in space allows complementary approaches to measuring the winds across the ocean and under many different types of conditions.

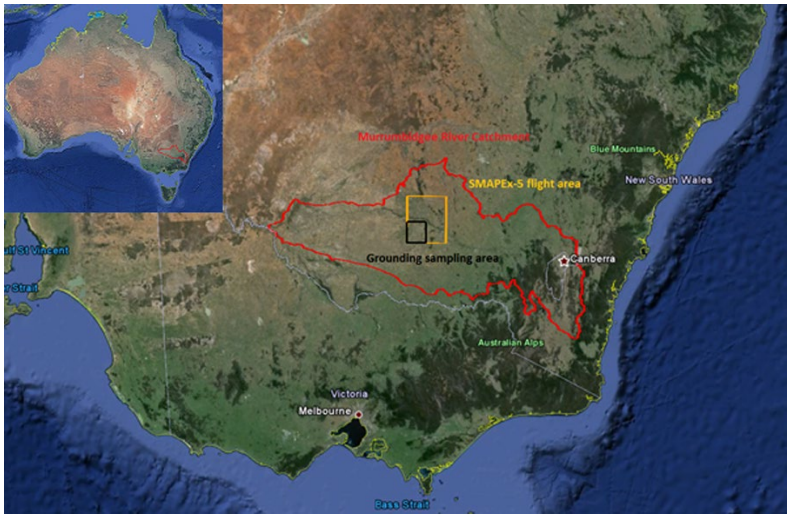


A single CYGNSS satellite. The top panels are all solar cells, except for the white strip in the middle, which contains a GPS antenna. **Image credit:** NASA

To learn about other aspects of the satellites and the science behind the missions, visit *earthobservatory.nasa.gov/blogs/fromthefield/category/cygnss*.

SMAPEx-5 Blog: Updates from the Field

The intent of this blog is to give live updates on progress of the fifth Soil Moisture Active Passive Experiment (SMAPEx-5) field campaign, being performed near Narrandera, New South Wales (NSW), Australia. These experiments support NASA's SMAP mission, launched January 31, 2015, to measure global soil moisture at a spatial resolution of 10-km (~6.2 mi). The first three field campaigns were focused on development and validation of prelaunch downscaling algorithms using airborne simulations of the SMAP data stream, while the fourth campaign [conducted in May 2015 (the austral autumn)] was the first real demonstration of how successful the SMAP mission is at mapping soil moisture at such high resolution. To further validate SMAP products under different soil moisture and vegetation conditions, this campaign was designed to resample that sampling area, but in the austral spring.



SMAPEx-5 will be carried out in Yanco, NSW, Australia from September 6-28, 2015. **Image credit:** Google Earth

For the latest news and updates, visit *smapex5.blogspot.com.au*. ■

[1] To learn more about CYGNSS, see "NASA Intensifies Hurricane Studies with CYGNSS" in the May-June 2013 issue of *The Earth Observer* [**Volume 25, Issue 3**, pp.12-21].

in the news

How Does NASA Study Hurricanes?

Max Gleber, NASA's Goddard Space Flight Center, max.gleber@nasa.gov

EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Hurricanes are the most powerful weather event on Earth. NASA's expertise in space and scientific exploration contributes to essential services provided to the American people by other federal agencies, such as hurricane weather forecasting.

The National Oceanic and Atmospheric Administration (NOAA) and the National Hurricane Center (NHC) use a variety of tools to predict storm paths. These scientists need a wealth of data to accurately forecast hurricanes. NASA satellites, computer modeling, instruments, aircraft, and field missions contribute to this mix of information to give scientists a better understanding of these storms.

NASA's Research Role

NASA's role as a research agency is to bring new types of observational capabilities and analytical tools to learn about the fundamental processes that drive hurricanes and work to help incorporate those data into forecasts. NASA collaborates with its interagency partners so that the nation benefits from our respective capabilities.

"Before we had satellites and aircraft, hurricanes would destroy entire cities, like the Labor Day Hurricane in Key West back in 1935," said **Gail Skofronick-Jackson** [NASA's Goddard Space Flight Center (GSFC)—*Global Precipitation Measurement (GPM) Project Scientist*]. "You would have no idea if a hurricane was coming until it was too late."

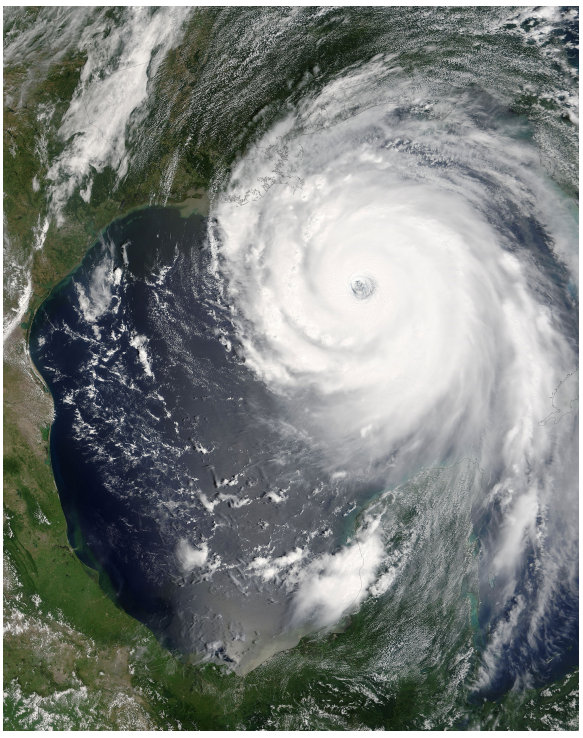
Hurricanes in the Atlantic Ocean can form when sub-Saharan thunderstorms travel westward with areas of lower pressure. These troughs are known as African Easterly Waves. Warm, moist air rises within the storm clouds, drawing air into the thunderstorms. Like an ice skater pulling in her arms to increase her spin, this inward moving air increases the rotation of the air within the storm cloud. Moving across the warm Atlantic, this cycle repeats on a daily basis, and, with a favorable environment, potentially accelerates to create a monstrous vortex powered by oceanic heat.

NASA uses an arsenal of instruments to learn more about how these storms progress as they form. These devices orbit Earth on a fleet of spacecraft, including Aqua, Terra, the GPM Core Observatory, Suomi National Polar-orbiting Partnership (NPP), Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), Jason-2, and CloudSat. "There are typically multiple instruments on every spacecraft with various purposes that often complement each other," said **Eric Moyer** [GSFC—*Earth Science Operations Manager*]. "We can see the progression of a storm from one day to the next using the Terra and Aqua satellites—a morning and afternoon view of every storm system, every day."

What NASA Studies

These instruments analyze different aspects of these storms, such as rainfall rates, surface wind speed, cloud heights, ocean heat, and environmental temperature and humidity. Observing these factors helps identify the potential for storm formation or intensification. Similarly, the data allow meteorologists to better predict where, when, and how hard hurricanes will strike land.

NASA's International Space Station Rapid Scatterometer (ISS-RapidScat) measures surface winds over the ocean and is used to gather data on tropical cyclones. This can show where in a hurricane the strongest winds occur. ISS-RapidScat continues a long satellite record of these observations that began with NASA's Quick Scatterometer (QuikSCAT) satellite.



This visible image of Hurricane Katrina was taken on August 29, 2005 at 05:16 UTC (1:16 AM EDT) by the MODIS instrument that flies onboard NASA's Aqua satellite as it approached landfall in Louisiana. **Image credit:** NASA Goddard MODIS Rapid Response Team

Scientists must completely understand a hurricane to predict its trajectory and strength. This means meteorologists must peer inside the cloud itself.

"Looking at the cloud structure can help us understand the storm's structure and location, which improves our forecasts," said **Michael Brennan**, [NOAA's NHC—*Senior Hurricane Specialist*]. "We heavily rely on the passive microwave imagers from satellites to see what is happening in the core of the storm."

Passive microwave imagers onboard the GPM Core Observatory and Suomi NPP missions can peer through cloud canopies, allowing scientists to observe where the water is churning in the clouds.

"Just like a doctor using x-rays to understand what's happening in the human body, our radiometers can pierce the clouds and understand the cyclone's structure," Skofronick-Jackson said. "We learn about the amount of liquid water and falling snow in the cloud. Then we know how much water may fall out over land and cause floods."

"Having satellites to watch the ocean is critical, and that will never change," Skofronick-Jackson said. "Radars on Earth can only see a certain distance out in the ocean, so without spacecraft, you would need radars on every ship. With satellite data informing computer models, we can predict the storms' paths, to the point where regions only need to evacuate half as much coastline as before. That's important, because it costs a lot of money to pack up, move to a hotel, and close down businesses."

Computer Modeling

Computer modeling is another powerful NASA research tool.

NASA's Global Modeling and Assimilation Office (GMAO) works to improve the understanding of hurricanes and assess models and procedures for quality. The GMAO helps to identify information that was missing and determines what services could be added to help future investigation and prediction of hurricane systems.

As NASA launches more sophisticated Earth-observing instruments, teams produce models with higher and higher resolutions, the ability to ingest such data, or the data assimilation procedure, increases. Each new instrument provides scientists and modelers a closer and more varied look at tropical cyclones. The higher the resolution of models and the increased capability of data assimilation systems, the easier it is to exploit data from satellite-borne instruments and to determine a hurricane's intensity and size in terms of things such as the wind field and cloud extent.

Airborne Missions

NASA also conducts field missions to study hurricanes. With an arsenal of instruments, ranging from radiometers that read moisture levels; lidars that measure aerosols, moisture, and winds; dropsonde systems to measure high-resolution profiles of temperature, pressure, moisture, and winds; to Doppler radar systems to map the three-dimensional precipitation and winds within storms. These instruments monitor the structure and environment of hurricanes and tropical storms as they evolve.

The most recent NASA field mission to study hurricanes was the Hurricane and Severe Storm Sentinel (HS3). For three consecutive years, the HS3 mission investigated the processes that underlie hurricane formation and intensity change in the Atlantic Ocean basin. The mission used the Global Hawk, a high-altitude long-endurance aircraft capable of flights of 26 hours at altitudes above 55,000 ft (16,764 m). Flying from NASA's Wallops Flight Facility, the uninhabited Global Hawks could cover the entire Atlantic Ocean, enabling measurements of storms at early stages in the central or eastern Atlantic or spending 12-18 hours over storms in the western Atlantic.

A Future Mission

In 2016 NASA is launching the Cyclone Global Navigation Satellite System (CYGNSS)—a constellation of eight small satellites. CYGNSS will probe the inner core of hurricanes in detail to better understand their rapid intensification. One advantage of CYGNSS is that it will collect frequent measurements within storms. This will allow CYGNSS to make accurate measurements of ocean surface winds both in and near the eye of the storm throughout the lifecycle of tropical cyclones. The goal is to improve hurricane intensity forecasts.

NASA data and research allows scientists to observe the fundamental processes that drive hurricanes. Meteorologists incorporate this satellite, aircraft, and computer modeling data into forecasts in the U.S. and around the world. ■

in the news

NASA Flies Stormy Kansas Skies this Summer for Science

Chris Rink, NASA's Langley Research Center, christopher.p.rink@nasa.gov

EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

When shall we three meet again in thunder, lightning, or in rain?... That will be ere the set of sun. – Opening lines from Shakespeare's "Macbeth."

Last month, NASA and its partners waited for the sun to go down over Oklahoma, Kansas, and Nebraska and the storms to come out in order to take a closer look at them with research aircraft.

The flights aimed to give scientists a better understanding of medium-size weather systems and the resulting thunderstorms—known as *mesoscale convective systems* (MCSs)—that form over the U.S. central Great Plains in the summertime. The research is part of a study called Plains Elevated Convection At Night (PECAN), funded by the National Science Foundation (NSF) with support from NASA, the National Oceanic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research (NCAR), and the Department of Energy (DOE).

Sunset behind NASA's DC-8 aircraft. **Image credit:** NASA

"The forecast for these nighttime thunderstorms have lots of uncertainty about how strong the storms will be or where the storms will go," said **Richard Ferrare** [NASA's Langley Research Center—*Senior Research Scientist*]. "What PECAN is trying to do is acquire a lot more detail data for predicting where these storms will form, how long they will last, and how much rain will come from the storm."

Unlike other parts of the U.S., summer thunderstorms across this region are most common after sunset. These nighttime storms may produce heavy rainfall that can be a significant portion of the yearly precipitation in the Great Plains.

Scientists understand why thunderstorms form during the day as rising warm air from the heated Earth's surface causes convection that can lead to thunderstorm development. Not so well understood is the appearance of thunderstorms after the sun has gone down and the land surface has cooled. The air that creates nighttime thunderstorms often originates in an elevated layer above the surface and is outside the reach of the usual surface-based weather monitoring instruments. This makes it difficult to predict the MCSs as a potential weather hazard and their impact on farming and water supplies.

To address this need, participants from 11 research laboratories and 27 universities began collecting storm data on June 1, 2015 based out of Hays, KS, using ground and air instruments to find out how and why nighttime thunderstorms form.

In addition to NASA and NOAA aircraft, researchers collected data from a third plane, the University of Wyoming King Air, ground-based instruments called PECAN Integrated Sounding Arrays, weather balloons, and fixed and mobile radars. NASA's Goddard Space Flight Center also provided ground-based monitoring equipment, the X-Band Atmospheric Doppler Ground-based Radar, and the Atmospheric Lidar for Validation, Interagency Collaboration and Education (ALVICE).

Based on the best information available, the PECAN scientists directed the planes and mobile ground units to areas where they thought the MCS would form while the fixed ground instruments were obtaining information about the background conditions.

As Sleepless as the Rain

Eight-hour flights for NASA's modified Douglas DC-8[1] jetliner, a flying laboratory supporting the PECAN mission, typically flew from late evening to early morning.

[1] The DC-8 is based at NASA's Armstrong Flight Research Facility, and supports NASA's Airborne Science Program in the Science Mission Directorate.

The aircraft carried atmospheric science instruments and investigators from NASA's Langley Research Center, NASA/Jet Propulsion Laboratory, and several universities and research labs.

For two-and-a-half weeks, home for the DC-8 and crew was the Salina Regional Airport in Salina, KS, centrally located in the Sunflower State and ideal for flights over the Great Plains. The plane began PECAN research flights on June 30. On July 10, at almost 30,000 ft (9144 m) somewhere over northern Kansas, Ferrare watched the data input from the Lidar Atmospheric Sensing Experiment (LASE) instrument on the DC-8.

From his seat in the midsection of the aircraft, he was two hours into a scheduled eight-hour flight that started at 8:00 PM local time. Ferrare rubbed his eyes, made notes in a small, green hard-cover notebook, and stared at two display screens. One was a representation of the data being collected real time by LASE. The second showed a simple aircraft icon drawing a line over a radar grid as the DC-8 flew near and around a large convection system drifting slowly south from Nebraska into Kansas.

"What we're trying to do right now is measure the inflow going into these developing storm systems," says Ferrare. "With the LASE instrument, we're able to measure water vapor profiles under the aircraft looking at the low-level flow going into this storm. So we're trying to characterize the environment where these are growing and developing, as well as the rain coming from the storm." Ferrare said there were a variety of storm types during the PECAN study—some fitting the profile, others not. "Which is good," he said. "It helps us to better develop models to account for variability that we often see in these storms."

Into Each Life Some Rain Must Fall

A study born in a hallway, a group of atmospheric scientists visiting NCAR were standing around chatting one day about the difficulty of studying nighttime thunderstorms and understanding why most of the rain in the central U.S. falls at night.

"The project expanded to include participation from NASA, NOAA, the DOE, and many universities from across the U.S. and Canada," said **Tammy Weckwerth** [NCAR—*PECAN Principal Investigator (PI)*]. As a researcher in NCAR's Earth Observing Laboratory, she concentrates on mesoscale meteorology, especially the relationship between the boundary layer and the initiation of thunderstorms.

Weckwerth said that the MCSs have a profound influence on agriculture in the region. Improved forecasting models would help farmers know when and where the thunderstorms will occur, how to make decisions on irrigation, or how and when to plant seeds.

"There's also the human safety factor with these severe nighttime systems," she said. "So, if we can have a better understanding and forecast warning time of the hazards such as flash flooding or high wind events and hail damage, then that will benefit society in general by getting improved and increased warning time so people can get to safety."

In addition to the effect it has on the region's hydrology, energy, and agriculture, the storms have a significant impact on public safety. During the second week of the DC-8 flights, an intense storm created a lightning strike that ignited a fire and gutted a home in nearby Wichita, KS, with an estimated $1 million in damages. Another lightning strike from the storm punched a hole in the north turret of the Friends University's historic clock tower in the same city. The Wichita Eagle newspaper noted that firefighters were alerted to 21 lightning strikes in the past 18 months—14 resulted in damage. PECAN research will influence the nation's forecasting and weather prediction capabilities through collaborative efforts between researchers and NOAA's National Severe Storms Laboratory.

The PECAN field mission wrapped up in mid-July.

Now that the data have been collected, the challenge, as Weckwerth puts it, is for the various science teams to collaborate and fit the pieces of the puzzle together to understand what was going on in the atmosphere prior to the storms forming, and during their evolution and dissipation. They will also look at how the stages produce the maximum rainfall in the region.

The collaborative efforts will last for years as the instrument PIs and students bring their data together. Each instrument will provide a different set of information about the atmosphere including the obvious air temperature, rainfall distribution, wind field, and water vapor profiles along with all the other observed variables, too. Putting that all together will help the scientists understand the physics of the atmosphere, what went into the evolution of these systems, and create better weather and climate models from the PECAN data.

Improved models mean better forecasts of the MCSs and thunderstorms.

"It's important because it affects people's lives," says Weckwerth, "whether they are farmers or truck drivers or anyone who is planning a picnic the next day, it goes to the very heart of what people need to know—that is—how much rain is going to fall? Will there be severe weather in my backyard? Everybody needs to know that, so they can live comfortably, peacefully, and safely." ■

in the news

NASA: California Drought Causing Valley Land to Sink

Alan Buis, NASA/Jet Propulsion Laboratory, alan.buis@jpl.nasa.gov

EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

As Californians continue pumping groundwater in response to the historic drought, the California Department of Water Resources (DWR) released a new NASA report showing land in the San Joaquin Valley is sinking faster than ever before, nearly 2 in (5 cm) per month in some locations.

The report, *Progress Report: Subsidence in the Central Valley, California*, prepared for the California DWR by researchers at NASA/Jet Propulsion Laboratory (JPL) is available at *water.ca.gov/groundwater/docs/NASA_REPORT.pdf*.

"Because of increased pumping, groundwater levels are reaching record lows—up to 100 ft (30 m) lower than previous records," said **Mark Cowin** [California Department of Water Resources—*Director*]. "As extensive groundwater pumping continues, the land is sinking more rapidly and this puts nearby infrastructure at greater risk of costly damage."

Sinking land, known as *subsidence*, has occurred for decades in California because of excessive groundwater pumping during drought conditions, but the new NASA data show the sinking is happening faster, putting infrastructure on the surface at growing risk of damage.

NASA obtained the subsidence data by comparing satellite images of Earth's surface over time. Over the last few years, interferometric synthetic aperture radar (InSAR) observations from satellite and aircraft platforms have been used to produce maps of subsidence with approximately centimeter-level accuracy. For this study, JPL researchers analyzed satellite data from Japan's Phased Array type L-band Synthetic Aperture Radar (PALSAR) [2006 to 2010]; and Canada's Radarsat-2 [May 2014 to January 2015], and then produced subsidence maps for those periods. High-resolution InSAR data were also acquired along the California Aqueduct by NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) [2013 to 2015] to identify and quantify new, highly localized areas of accelerated subsidence along the aqueduct that occurred in 2014. The California Aqueduct is a system of canals, pipelines, and tunnels that carries water collected from the Sierra Nevada Mountains and Northern and Central California valleys to Southern California.

Using multiple scenes acquired by these systems, the JPL researchers were able to produce time histories of subsidence at selected locations, as well as profiles showing how subsidence varies over space and time.

"This study represents an unprecedented use of multiple satellites and aircraft to map subsidence in California and address a practical problem we're all facing," said report co-author **Tom Farr** [JPL—*Research Scientist*]. "We're pleased to supply the California DWR with information they can use to better manage California's groundwater. It's like the old saying: 'you can't manage what you don't measure'."

Land near Corcoran in the Tulare basin sank 13 in (33 cm) in just eight months—about 1.6 in (4 cm) per month. One area in the Sacramento Valley was sinking approximately 0.5 in (1.3 cm) per month, faster than previous measurements.

Using the UAVSAR data, NASA also found areas near the California Aqueduct sank up to 12.5 in (32 cm), with 8 in (20 cm) of that occurring in just four months of 2014—see **Figure**.

"Subsidence is directly impacting the California Aqueduct, and this NASA technology is ideal for identifying which areas are subsiding the most in order to focus monitoring and repair efforts," said study

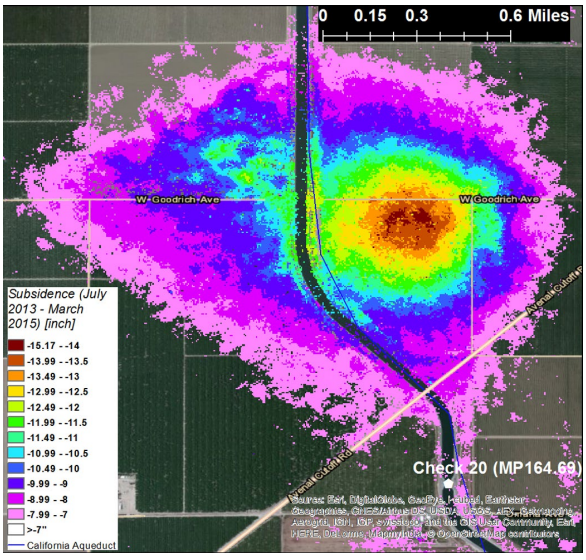


Figure. NASA's UAVSAR measured cumulative vertical ground movement impacting the California Aqueduct near Huron and Kettleman City from July 2013 to March 2015. The overlay shows areas where subsidence exceeded 7 in (17.8 cm). UAVSAR pixel resolution is 20-by-20 ft (6-by-6 m). **Image credit:** NASA/JPL-Caltech

co-author **Cathleen Jones** [JPL—*Research Scientist*]. "Knowledge is power, and in this case knowledge can save water and help the state better maintain this critical element of the state's water delivery system." UAVSAR flies on a C-20A research aircraft based at NASA's Armstrong Flight Research Center facility.

The increased subsidence rates have the potential to damage local, state, and federal infrastructure, including aqueducts, bridges, roads, and flood control structures. Long-term subsidence has already destroyed thousands of public and private groundwater well casings in the San Joaquin Valley. Over time, subsidence can permanently reduce the underground aquifer's water storage capacity.

"Groundwater acts as a savings account to provide supplies during drought, but the NASA report shows the consequences of excessive withdrawals as we head into the fifth year of historic drought," Cowin said. "We will work together with counties, local water districts, and affected communities to identify ways to slow the rate of subsidence and protect vital infrastructure such as canals, pumping stations, bridges, and wells."

NASA will also continue its subsidence monitoring, using data from the European Space Agency's recently launched Sentinel-1 mission to cover a broader area and identify more vulnerable locations.

The California DWR also completed a recent land survey along the Aqueduct—which found 70-plus mi (113-plus km) in Fresno, Kings, and Kern counties sank more than 1.25 ft (0.4 m) in two years—and will now conduct a system-wide evaluation of subsidence along the California Aqueduct and the condition of State Water Project facilities. The evaluation will help the department develop a capital improvement program to repair damage from subsidence. Past evaluations found that segments of the Aqueduct from Los Banos to Lost Hills sank more than 5 ft (1.5 m) since construction.

NASA and the Indian Space Research Organisation (ISRO) are jointly developing the NASA-ISRO Synthetic Aperture Radar (NISAR) mission. Targeted to launch in 2020, NISAR will make global measurements of the causes and consequences of land surface changes. Potential areas of research include ecosystem disturbances, ice sheet collapse, and natural hazards. The NISAR mission is optimized to measure subtle changes of Earth's surface associated with motions of the crust and ice surfaces. NISAR will improve our understanding of key impacts of climate change and advance our knowledge of natural hazards. ■

Continuity Assured: The First Postlaunch MODIS/VIIRS Science Team Meeting Summary

continued from page 18

For further information about the MODIS/VIIRS meeting *modis.gsfc.nasa.gov/sci_team/meetings/201505/plenary.php* to view the PowerPoint and/or pdf files for many of the presentations.

In her closing remarks, **Paula Bontempi** highlighted further development needs and issues for the MODIS and VIIRS science teams to consider. An overarching goal is to maintain continuity and to produce Earth System Data Records for the research and application communities. Algorithm developers and validation investigators should continue to address important deficiencies, such as uncertainties in key data products.

Continuity of data products is a priority, but *orphan products*—data products that aren't being maintained by a principal investigator—need to be considered also. Science teams should consider how to facilitate interdisciplinary algorithms and science, and how to work with and respond to the needs of the broader communities, e.g., users. Bontempi encouraged the establishment of user-friendly websites, with coordination among discipline leads, project scientists, and principal investigators to inform the user community about the latest algorithms and their documentation. Finally, subsequent data products should clearly state uncertainties and relevance to science and benefits to society. ■

NASA Earth Science in the News

Maria-Jose Vinas Garcia, NASA's Earth Science News Team, maria-jose.vinasgarcia@nasa.gov

Global Sea Levels Have Risen 8 cm Since 1992, NASA Research Shows[1], July 26; *Reuters*. Sea levels worldwide have risen an average of nearly 8 cm (3 in) since 1992 because of warming waters and melting ice, a panel of NASA scientists has reported—see **Figure 1**. Based on an analysis of 23 years of satellite data, the changes are not uniform: Some areas show sea levels rising more than 25 cm (10 in) and other regions, such as along the U.S. west coast, falling. Scientists believe ocean currents and natural cycles are temporarily offsetting a sea-level rise in the Pacific, and the U.S. west coast could see a significant rise in sea levels in the next 20 years. "People need to understand that the planet is not only changing, it's changed," said **Tom Wagner** [NASA Headquarters (HQ)—*Program Manager for Cryosphere Science*], who continued, "If you're going to put in major infrastructure like a water treatment plant or a power plant in a coastal zone...we have data you can now use to estimate what the impacts are going to be in the next 100 years." **Michael Freilich** [NASA HQ—*Director of NASA's Earth Science Division*] added that low-lying regions, such as Florida, are especially vulnerable.

[1] This news story was one of many that resulted from the NASA-wide, Sea-Level Rise media campaign. Other relevant coverage included articles in the *Washington Post, Los Angeles Times, Forbes,* and *The Guardian*.

China Pollution Crosses Sea, Hampers Air Cleanup Effort in the U.S., August 10; *Bloomberg Business*. Chinese air pollution is blowing across the Pacific Ocean and partly offsetting clean air measures taken in California, according to a group of Dutch and U.S. researchers that included NASA authors. According to the study, which was published in the journal *Nature Geoscience*, more than two-fifths of the expected benefits of antipollution controls in the western U.S. were canceled out by rising ozone pollution from China. The research highlights the need for countries around the world to collaborate in combating air pollution, because the effects can be felt beyond the boundaries of any single nation. While ozone is important in the upper atmosphere to protect Earth's biological systems from harmful ultraviolet radiation, at ground level it's a pollutant that causes respiratory problems in humans and damage in plants. Further, in the lower atmosphere, or troposphere, it acts as a greenhouse gas.

Missing: One Year's Worth of California Rain, July 31; *Climate Central*. A new study has concluded that the amount of rain that California has missed out on since the beginning of its record-setting drought in 2012 is about the same amount it would see, on average, in an entire year—see **Figure 2**. The study's researchers, which include scientists at NASA's Goddard Space Flight Center, pin the reason for the lack of rain on the absence of the intense rainstorms ushered in by so-called

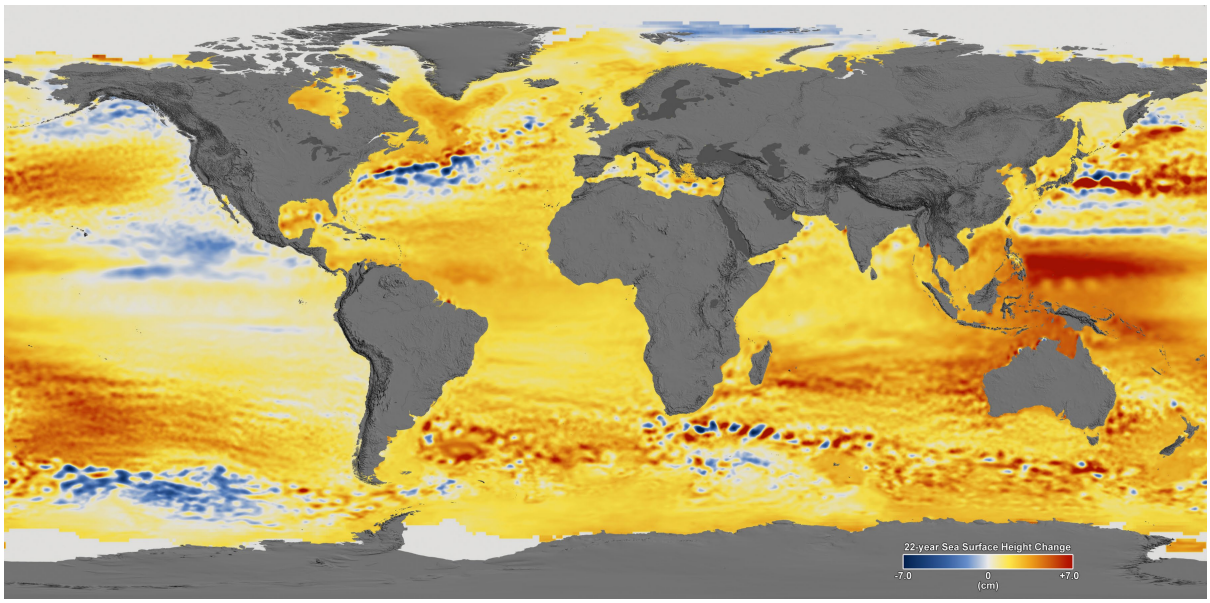


Figure 1. This map shows total global sea-surface height change between 1992 and 2014. Note that the changes are not uniform. Orange shades represent areas where sea levels have risen, while blue shades represent areas where sea level has fallen. **Image credit:** NASA's Scientific Visualization Studio (SVS)

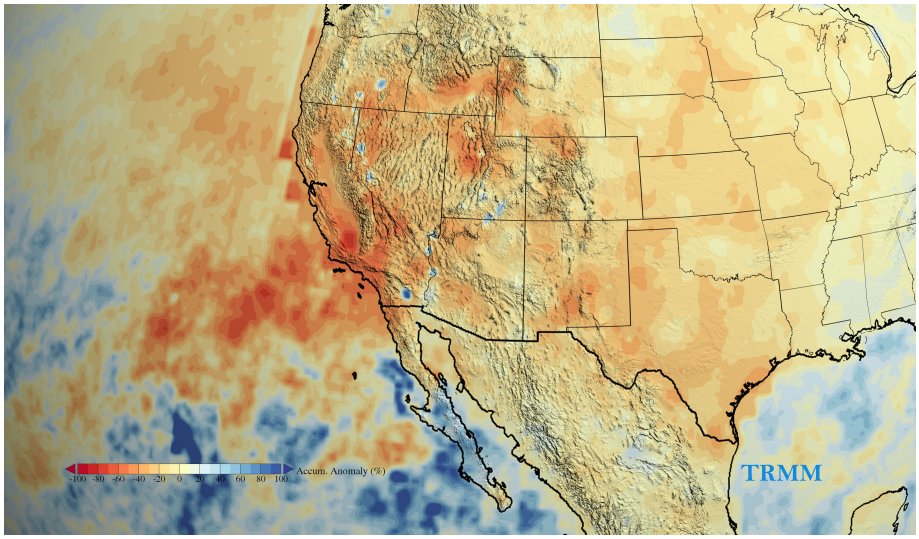


Figure 2. In an average year, California sees about 20 in (51 cm) of rain. Using data from TRMM and recreated climate records from MERRA, researchers have determined that about that much rainfall is "missing" as a result of California's multiyear drought, which began in 2012. That is, the accumulated rainfall deficit from 2012 through 2014 is roughly equal to the amount of rain California typically receives in an entire year. The map at the left shows TRMM data; the MERRA results are found at *svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4327*. **Image credit**: NASA's SVS

atmospheric rivers, ribbons of very moist air that can funnel water vapor from the tropics to California during its winter rainy season. Overall, the research found that California can experience multi-year dry periods, like the current one, and then periods where rains vary by 30% from year to year. Those wet and dry years typically cancel each other out. The new study looked at satellite measurements of rainfall from NASA's Tropical Rainfall Measuring Mission (TRMM) satellite, as well as a recreated climate record from the Modern Era Reanalysis for Research and Applications (MERRA). Observations and model data were both used to gauge how much California's annual precipitation varied and how much it was in the hole after four years of drought. The researchers found that in an average year, the state receives about 20 in (51 cm) of rain; it turns out that's also about the amount of rain missing since 2012.

Ocean 'Weather Balloons' Detect Cause of Global Warming Pause, July 11; *Los Angeles Times*. Sea temperature data, some collected by a fleet of drifting and diving probes, shows that a decade-long slowdown in global surface warming masked a coincident rise in ocean temperature below 300 ft (91 m). The finding, which was published recently in the journal *Science*, is the latest paper to take on the controversial topic of the global warming pause, or hiatus. In the study, climate scientists **Veronica Nieves**, **Josh Willis**, and **William Patzert** [all from NASA/Jet Propulsion Laboratory] pored over sea temperature data dating back two decades. A large portion of this information was collected by the *Argo array*—a network of more than 3000 automated sea probes that can dive deeper than a mile (1.6 km), take temperature and salinity readings, and then return to the surface where they transmit the information to orbiting satellites. The data show that during a portion of the hiatus—from roughly 2003 to 2013—sea surface temperatures in the Pacific and Indian Oceans rose more slowly than they had in previous years. However, heat actually accumulated in a layer of water just below the surface, at depths between 300 and 1000 ft (91 and 305 m, respectively). The study concludes that this layer of warming indicates that even though the rise in global average surface temperature has slowed, the ocean continues to absorb heat generated by atmospheric greenhouse gases.

***Drought is Causing California's Central Valley to Sink**, August 21, *The Weather Channel*. As the drought in California continues to put a strain on the state's water supply, another long-standing issue comes into play: The ground is sinking. According to a report by NASA/Jet Propulsion Laboratory for the California Department of Water Resources (DWR), an occurrence known as *subsidence* has been causing portions of the San Joaquin Valley in California's Central Valley to sink nearly 2 in (5 cm) per month between May 3, 2014 and January 22, 2015. Subsidence is the gradual caving in or sinking of an area of land. In California the ground is collapsing because farmers have been continuously pumping out groundwater in order to keep their crops alive through drought conditions. When this water is pumped out of the aquifer, the clay in between the pockets of water collapses and causes the ground to compress. The NASA report also states that the land near Corcoran, in the Tulare basin, sank 13 in (33 cm) within an 8-month period, and that a stretch near the California Aqueduct—one of the main arteries of the State Water Project—sank 8 in (20 cm) over a 4-month stretch last year.

*See news story in this issue.

*Interested in getting your research out to the general public, educators, and the scientific community? Please contact **Samson Reiny** on NASA's Earth Science News Team at **samson.k.reiny@nasa.gov** and let her know of upcoming journal articles, new satellite images, or conference presentations that you think would be of interest to the readership of **The Earth Observer**.* ■

NASA Science Mission Directorate – Science Education and Public Outreach Update

Theresa Schwerin, Institute for Global Environmental Strategies, theresa_schwerin@strategies.org
Morgan Woroner, Institute for Global Environmental Strategies, morgan_woroner@strategies.org

NASA Postdoctoral Fellowships

Audience: Postdoctoral students (doctoral degree attained by the time the appointment begins).

Application Deadline: November 1, 2015

The NASA Postdoctoral Program (NPP) offers scientists and engineers unique opportunities to engage in NASA research in Earth science, heliophysics, astrophysics, planetary science, astrobiology, space bioscience, aeronautics and engineering, human exploration and operations, and space technology.

Awards: Annual stipends start at $53,500, with supplements for specific degree fields and high cost-of-living areas. There is an annual travel budget of $8000, a relocation allowance, and financial supplement for health insurance purchased through the program. Approximately 90 fellowships are awarded annually.

Eligibility: U.S. citizens, lawful permanent residents, or foreign nationals eligible for J-1 status as a research scholar may apply. Applicants must have completed a PhD or equivalent degree before beginning the fellowship, but may apply while completing the degree requirements. Fellowships are available to recent or senior-level PhD recipients.

To obtain more information and to apply for this exciting opportunity, visit *nasa.orau.org/postdoc*.

"Where Over the World Is Astronaut Scott Kelly?" Trivia Contest

During his year-long stay on the International Space Station, astronaut **Scott Kelly** wants to test your knowledge of the world through a geography trivia game on *Twitter*. Traveling more than 220 mi (354 km) above Earth, and at 17,500 mph (28,163 km/hr), he circumnavigates the globe more than a dozen times a day. This gives Kelly the opportunity to see and photograph various geographical locations on Earth. In fact, part of his job while in space is to capture images of Earth for scientific observations.

Follow *@StationCDRKelly* on *Twitter*; where each Wednesday, Kelly will tweet a picture and ask the public to identify the place depicted in the photo. The first person to identify the place correctly will win an autographed copy of the picture. Kelly plans to continue posting weekly contest photos until he returns from the space station in March 2016.

For more information, visit *www.nasa.gov/feature/where-over-the-world-is-astronaut-scott-kelly*.

To learn more about the One-Year Mission, visit *www.nasa.gov/content/one-year-crew*.

Wavelength Feature: 'The Dynamic Earth' Video

With the United Nations Office for Outer Space Affairs *Why Space Matters on Earth (www.unoosa.org/oosa/contests/whyspacematters/index.html)* photo competition in full swing, *The Dynamic Earth* video will give you some great ideas about how NASA uses Earth observations to monitor our ever-changing planet to improve our lives and safeguard our future. Get inspired by this short film and share photos that show your appreciation for NASA's eyes in the sky! To learn more and to watch the video, visit *www.nasa.gov/topics/earth/features/dynamic-earth.html*.

New on the Climate Kids Website: Paper or Plastic?

When we go to the grocery store, we're often asked by the checkout clerk, *"Paper or plastic?"* What things should you consider before you answer? And what is the best answer to that question? Find out at *climatekids.nasa.gov/paper-or-plastic*.

New on the SciJinks Website: Drought

It's been called the California drought, but it affects much of the western U.S. For more than four years, there has been little rain and snow in the region—but that's just part of the problem. Learn more at *scijinks.gov/drought*. ■

EOS Science Calendar

October 13–16, 2015
Sounder Science Team Meeting, Greenbelt, MD.
airs.jpl.nasa.gov/events/35

October 19–23, 2015
Ocean Surface Topography Science Team Meeting, Washington, DC.

November 10–13, 2015
SORCE Sun-Climate Symposium, Savannah, GA.
go.nasa.gov/1zRx2Hj

December 1–3, 2015
CLARREO Science Definition Team Meeting, Hampton, VA.
clarreo.larc.nasa.gov/events.html

January 6–8, 2016
ESIP Federation Winter Meeting, Washington, DC.
commons.esipfed.org/2016WinterMeeting

Global Change Calendar

November 4–5, 2015
Mapping Urban Areas from Space, Frascati, Italy.
earth.esa.int/web/guest/pi-community/events/-/article/mapping-urban-areas-from-space-muas-2015-conference

November 9–13, 2015
GEO-XII Plenary and Ministerial Summit, Mexico City, Mexico.
earthobservations.org/index.php

November 30–December 11, 2015
COP-21, Paris, France.
www.cop21paris.org

December 14–18, 2015
American Geophysical Union Fall Meeting, San Francisco, CA.
fallmeeting.agu.org/2015

January 10-14, 2016
American Meteorological Society Annual Meeting, New Orleans, LA.
annual.ametsoc.org/2016

Undefined Acronyms Used in the Editorial and Article Titles

CALIPSO	Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations
CNES	Centre National d'Études Spatiale
EO-1	Earth Observing-1
EOS	Earth Observing System
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GRACE	Gravity Recovery and Climate Experiment
GPM	Global Precipitation Measurement
ISS–RapidScat	International Space Station Rapid Scatterometer
JPSS	Joint Polar Satellite System
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanographic and Atmospheric Administration
NPP	National Polar-orbiting Partnership
OSTM	Ocean Surface Topography Mission
QuikSCAT	Quick Scatterometer
SORCE	Solar Radiation and Climate Experiment
SMAP	Soil Moisture Active/Passive
TOPEX	Ocean Topography Experiment
TRMM	Tropical Rainfall Measuring Mission
VIIRS	Visible Infrared Imaging Radiometer Suite

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Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 15th of the month preceding the publication—e.g., December 15 for the January–February issue; February 15 for March–April, and so on.

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